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INDUCTIVE AERIALS IN MODERN BROADCAST RECEIVERS

I. BRIEF HISTORY AND GENERAL DESCRIPTION

II. TECHNICAL ASPECTS OF INDUCTIVE AERIALS

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*After the broadcast receiver had grown out of the amateur stage and began to find its way into every home, one of the problems arising was that of the aerials. In the large cities, where a large proportion of the population is housed, as it were, piled up in layers, a veritable forest of aerials began to appear on the roof tops. To combat this eyesore, one of the solutions sought was the system of one central aerial, feeding a number of receivers via a high-frequency booster *).*

The fact, however, that the normal roof aerial (T.V. aerials will not be considered here) has largely disappeared, is due to the fact that nowadays a large public is satisfied with a small indoor aerial, strung in the room. With the high sensitivity of the modern set, a reasonable signal strength can be obtained with such a room aerial, but all too often it is marred by local interference. Already before the war, it was realized that a properly designed inductive or frame aerial has relatively a far smaller sensitivity to interference than a (capacitive) room aerial. Receivers incorporating one or more inductive aerials have been manufactured on a large scale in the last few years. The development of the material Ferroxcube has been of great importance in this respect.

The first part of the article below gives a general review of the development of the inductive aerial. The second part enters further into various technical details.

I. BRIEF HISTORY AND GENERAL DESCRIPTION

Advantages of an inductive aerial over a capacitive aerial

When considering the course of development of the normal broadcast receiver over the last 15 years, the important part played by progress in component manufacture should be noted. The refinement of manufacturing methods and the application of new materials have made it possible to make many component parts smaller, cheaper, and often of a better quality.

The magnetic material Ferroxcube has contributed significantly to these developments. Not only does it permit the manufacture of excellent H.F. and I.F. transformers of small dimensions ¹⁾, but

it has also led to the design of frame aerials as an intrinsic part of the radio receiver.

In the course of the years various aspects of the frame aerial have been discussed in this Review. The application of its directional effect, for the location or direction finding of ships and aircraft ²⁾ and its use for the reduction of interference from unwanted transmitters ³⁾ are well known. The frame aerial is also ideal for measuring the field strength of not-too-short waves ⁴⁾, owing to the fact that it gives excellently reproducible results and that its effective height can be calculated with great accuracy.

*) J. van Slooten, The communal aerial, Philips tech. Rev. 1, 246-251, 1936.

1) W. Six, Some applications of Ferroxcube, Philips tech. Rev. 13, 301-311, 1951/52.

2) See for example Philips tech. Rev. 2, 184-190, 1937.

3) P. Cornelius and J. van Slooten, Installations for improved broadcast reception, Philips tech. Rev. 9, 55-63, 1947.

4) M. Ziegler, A recording field strength meter of high sensitivity, Philips tech. Rev. 2, 216-223, 1937.

Aerials of this kind in broadcast receivers, are not of course used to determine the direction of the transmitter, or to apply a signal of accurately reproducible strength to the input of the receiver, but to obtain reception free of interference, in particular, local interference caused by electrical apparatus, such as motors, switches, etc. As demonstrated by Cornelius⁵), a frame aerial is less sensitive to such interference than an ordinary, capacitative aerial of the same effective height. This phenomenon can be briefly explained as follows: If a transmitter is received at a distance which is great with respect to the wavelength, then the receiver is situated in what is called the radiation field of the transmitter.

electric and the magnetic field strengths of the disturbance is likewise 120π . It is found, however, that for waves longer than 200 m, the ratio E/H from nearby sources of interference is far greater than 120π . An inductive aerial, therefore, will receive correspondingly less of this type of interference than a capacitative aerial.

It follows from the above that it is desirable for an inductive aerial to be free of all capacitative sensitivity or, as it is generally expressed, it should show no "aerial-effect". Means to combat this effect have already been described in this Review⁶), viz: symmetrical construction (centre of the inductive aerial earthed), electrical screening, and re-

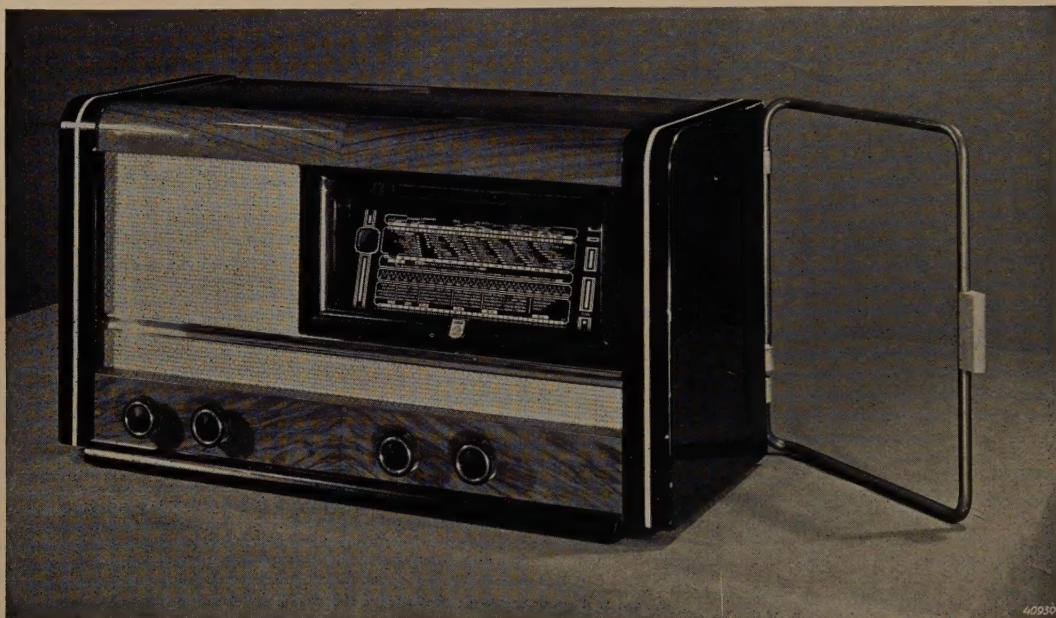


Fig. 1. Philips de-luxe receiver 902 A (1939), equipped with a single-loop frame aerial.

In this field there exists a certain fixed ratio between the strengths of the electric and the magnetic alternating fields at the position of the receiver, viz. the electric field strength E (expressed in volts per metre) is $4 \pi c \times 10^{-7}$, i.e. approximately 120π times the value of the magnetic field strength H (in amperes per metre); c being the velocity of light (in metres/sec). Since a capacitative aerial reacts to the electric component of the radiation field, whereas an inductive aerial reacts to the magnetic component, it will be clear that a local source of interference will have the same effect on both types of aerials only if the ratio E/H between the

duction of the number of turns. The first remedy alone is insufficient, as symmetry can never be adequately realized in practice. The second has the drawback that the screening considerably increases the minimum capacitance (so that the wavelength range of an ordinary tuning capacitor becomes very limited). The third remedy, however, is very effective, because the aerial-effect is proportional to the self-inductance of the aerial, and thus to the square of the number of turns n , whereas the voltage induced by the alternating magnetic field is proportional to n . This led Cornelius to the construction of a frame with only one turn⁶). It was applied in the Philips

⁵) P. Cornelius, The sensitivity of aerials to local interferences, Philips tech. Rev. 6, 302-308, 1941.

⁶) P. Cornelius, The aerial effect in receiving sets with loop aerial, Philips tech. Rev. 7, 65-73, 1942.

receiver, type 902 A (*fig. 1*). This de-luxe set was marketed in 1939 and may be considered as the forerunner of the present frame-aerial receivers.

The general introduction of inductive aerials in mains-fed receivers ⁷⁾ is a consequence of a number of factors:

- a) The use of all kinds of electrical appliances is steadily increasing, resulting in increased mains-interference.
- b) The population in the large towns becomes more and more concentrated, so that a relatively greater number of wireless sets are used in surroundings with considerable interference.
- c) Many local authorities have enacted legislation against the unlimited erection of roof aerials, so the use of (capacitive) room aerials has become more common. Although several broadcasting stations can be received with sufficient strength (thanks to powerful transmitters and sensitive receivers), a room aerial leaves much to be desired as regards freedom from interference.
- d) Small receivers, with dimensions of about $20 \times 30 \times 15$ cm, have become very popular. One of their most attractive features is that they are easily transportable from one place to another, and they should therefore not be bound to one spot by an aerial connection.
- e) The frequency allotment in the medium wave range according to the Copenhagen plan (1950) has not been universally accepted, with the result that many transmitters, especially in the evenings, are jamming each other's broadcasts. The directional effect of inductive aerials can be most useful to avoid interference of this type.

Development in Europe and the U.S.A.

Bearing these factors in mind it is of interest to note that the inductive aerial has developed along different lines in different countries. In Holland, after the appearance of the receiver 902 A with its single-loop aerial, several years passed before this principle was further applied in practice, due principally to interruption of development by the war. Moreover, the construction was considered too expensive and the hinged frame (*fig. 1*) did not enhance the appearance and limited the positioning of the set.

Paradoxically, the stimulus to further development came from receivers in the lowest price class. The dimensions of a set of this kind were small and the weight was low, as the tubes were directly fed

from the mains without the use of a transformer. These properties made the set very suitable for use wherever mains supply was available, provided only it had its own aerial.

In the U.S.A., where receivers of this type rapidly became popular (at one time they sold for \$ 10 to \$ 15), they were equipped with a frame aerial. The coil of the first tuned circuit was in the form of a fairly large conducting spiral, cemented to the rear panel of the set; an easily manufactured frame aerial was thus obtained, eminently suitable for mass production. This type of frame aerial worked very satisfactorily in the small American receivers, and is still being used on a large scale.

During the development of these small receivers in Europe it was soon found undesirable, however, to adopt this design without modification, due to the greater diversity of wavelengths in Europe than in the U.S.A. In the U.S.A., there is a large network of medium-wave stations (many of them transmitting identical programmes) but long-wave broadcasting stations are unknown. The small American receivers are therefore made for medium wave reception only, whereas European receivers require additional facilities for receiving long-wave stations. There is, moreover, the fact that in Europe short-wave reception is also considered desirable — the listening public has become accustomed to this facility and therefore demands it even in a small set.

If a small set is to receive these three ranges with a frame aerial, the best results are obtained if there is a separate frame for each range. This would mean incorporating three frame aerials in one set. Due to the compact construction of the whole, a certain inter-coupling of the frames is inevitable. A consequence of this is that if the set is tuned, for example, to a medium-wave station, the self-capacitance of the long-wave aerial forms a parasitic absorption circuit, which introduces losses. If, to avoid this, the long-wave aerial is connected in parallel with the medium-wave aerial, the total self-capacitance assumes such a value that the range of an ordinary tuning capacitor does not cover the entire medium-wave band.

This applies particularly if the self-capacitance is already large due to electrical screening of the frame aerial. As mentioned before, such screening is desirable in order to reduce the sensitivity to interference (cf. the article ⁶⁾), especially with long-wave reception ⁸⁾. In this respect, too, the situation for small receivers is less favourable in Europe than in America.

⁷⁾ Battery sets, to which quite different considerations apply, will not be discussed here.

⁸⁾ L. Blok, Combating radio interferences, Philips tech. Rev. 4, 237-243, 1939.

All these difficulties made the American design less suitable for small European sets. Neither was the one-loop frame aerial suitable, since it necessitated an h.f. transformer, which at that time was too expensive a component. For these small receivers it was necessary to resort to a small capacitive aerial. This took the form of a strip of metal or metallized paper fitted on the inside of the cabinet, and served for all three wavelength ranges ("Philetta" 209 U).

With regard to their sensitivity to mains interference, the American type of multi-turn frame aerial and the "Philetta" type of capacitive aerial are nearly identical⁵⁾ (fig. 2); it was found that in the small American receivers, the capacitive component of the total reception was about as great as that of the above capacitive aerial (approx. 12 pF). This demonstrates how seriously aerial-effect in a frame aerial can increase the sensitivity to mains interference. The performance of the receivers with the small capacitive aerial, may be summarized as follows:

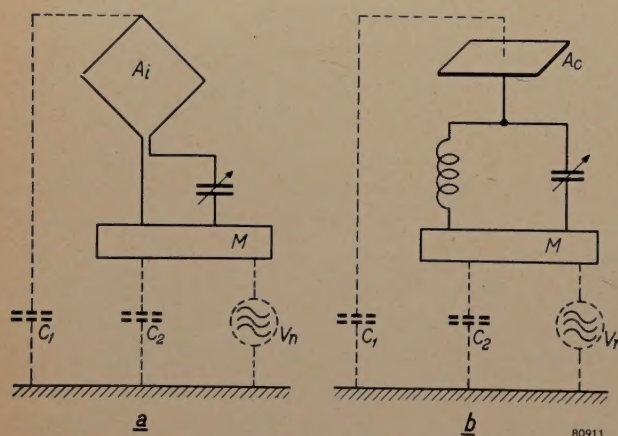


Fig. 2. Schematic representations of (a) receiver with inductive aerial (A_i), and (b) receiver with capacitive aerial (A_c). C_1 capacitance between aerial and surroundings, C_2 capacitance between chassis and earth, V_n sources of interference, M chassis.

- a) In the short-wave range, surprisingly good; practically no mains interference.
- b) For medium wavelengths, reception quality about equal to the small American sets with (non-screened) frame aerial: very good at night, but during the day, when listening to remote stations, a fairly high interference level which sounds like noise.
- c) On long waves, generally excessive interference; in specific centres of interference, hardly any reception was possible, unless the field of the transmitter was extremely strong.

As is shown in fig. 3, mains interference can be

divided into that from specific sources such as vacuum cleaners, switches, etc., and a nearly continuous spectrum of interference of uncertain origin,

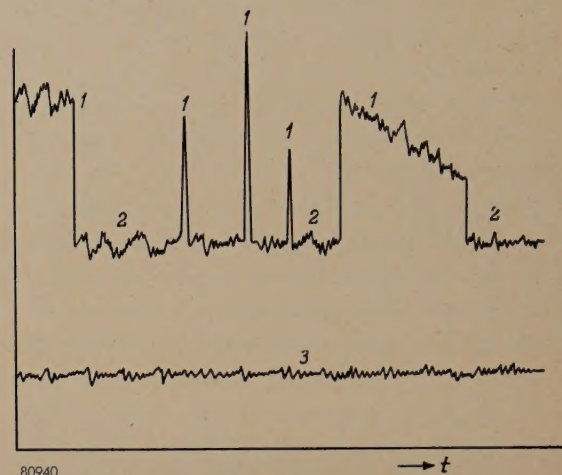


Fig. 3. Various interference voltages as functions of time (shown schematically). 1 interference from electric motors, switches, etc. 2 continuous interference pattern, often of unknown origin. 3 noise.

generally at a lower level. This spectrum of interference, mentioned under *b*, is similar to noise (hiss); in fact, it is difficult to distinguish between them. Actually, the interference spectrum sounds rather more "coarse grained" than the real noise and its intensity diminishes at increasing frequency⁸⁾.

It has further been observed that outside densely populated areas the specific interference is considerably weaker, but that the continuous spectrum of interference may be substantially present without any apparent source.

"Philetta" receiver with single-loop frame

In order to improve reception in the medium and long ranges, a receiver was developed in 1949, (the BX 290 U, also in the "Philetta" class), incorporating a single-loop frame aerial. It was thus, about ten years after the introduction of the single-loop frame aerial in the de luxe set 902 A, that it made its come-back in one of the lowest-priced receivers. This course of events is an example of how a basically sound idea may be shelved for years until suitable technological facilities become available for its exploitation. Because of the small self-inductance of a single-loop aerial a step-up transformer is necessary to couple it to the tuning capacitor of the input circuit (fig. 4). In the 902 A set this transformer was a quite expensive component. However, by using a small Ferroxcube rod as a core⁹⁾ it is possible to reduce the dimensions dras-

⁹⁾ It should be noted that as early as 1946, Ferroxcube was used on a small scale for this purpose; cf. page 63 of the article referred to in ³⁾.

tically, and hence, also the price. This development has enabled the interference-free frame aerial of few turns to find a place in receivers in the lower price brackets.

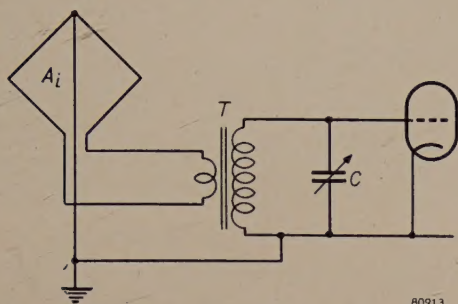


Fig. 4. A_i single-loop frame aerial. T h.f. step-up transformer. C tuning capacitor.

In the BX 290 U, the loop is in the form of an aluminium strip bent around the chassis (fig. 5). The small size of this radio means that the whole set can be easily turned; the need for a hinged construction is therefore dispensed with and the whole design is thereby considerably simplified. Fig. 5 shows how the frame has been built-in to the chassis. The mid-point of the loop is firmly screwed to the chassis, primarily for mechanical rigidity but also to further reduce the remaining small aerial-effect (see ⁶).

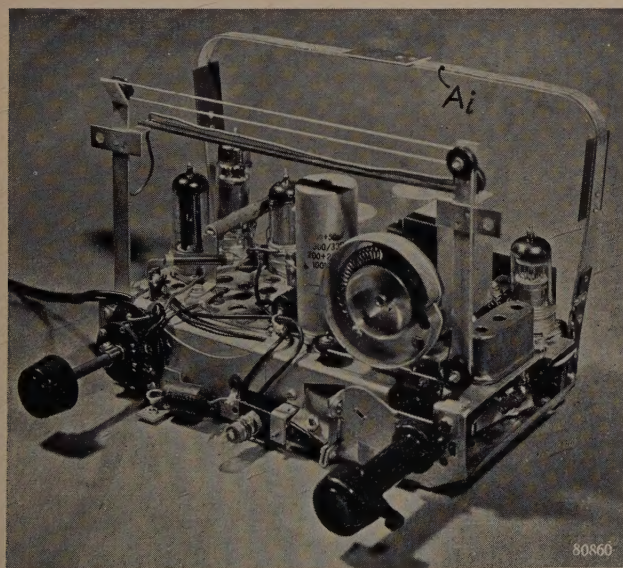


Fig. 5. Chassis of the Philetta BX 290 U receiver (1949). A_i single-loop frame aerial consisting of an aluminium strip.

Short waves are received with a small capacitive aerial (metal plate inside the receiver), which as mentioned above, is very effective for the short waves.

Modern inductive aerials

Frame aerials with few turns in larger receivers

After the single-loop frame had proved a success in the smaller sets, attempts were made to use it in larger receivers. The initial experiments, however, were disappointing: after tuning to moderately strong station, the "noise-like" interference was far stronger than with sets of the "Philetta" type, in spite of the greater loop surface in the larger set. The cause of this interference was the mains transformer, a component not present in the smaller sets, but necessary for several reasons in the larger receivers. It was found that the magnetic field of the mains transformer induced an interference spectrum in the frame aerial as soon as the primary was connected to the mains. Since the transformer consists of several layers of windings, each being coupled inductively and capacitatively to each other, the transformer contains a large number of oscillatory circuits. Many of these have resonance frequencies within the broadcasting range. When the transformer is connected to the mains, these oscillatory circuits are excited (even if a filter suppressing the high frequencies is incorporated between mains and transformer) and oscillate at their own fundamental frequencies. The result is a near-continuous interference spectrum, the amplitude of which diminishes at higher frequencies. The greatest trouble is therefore experienced in the long-wave range.

This interference can be effectively suppressed by means of a short-circuited copper strip surrounding the transformer (fig. 6). This strip serves as a short-circuited winding for the stray field of the transformer.

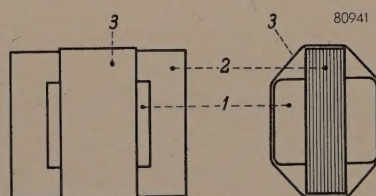


Fig. 6 Mains transformer (1 coil, 2 core) provided with a closed copper loop (3) which prevents the stray field of the transformer from inducing an interference voltage in the frame aerial.

After the introduction of the short-circuit winding, there remained for the larger sets the problem of the directional effect. Since the primary reason for incorporating an inductive aerial in a receiver is the reduction of mains interference, the directional effect is considered a nuisance rather than an advantage. After the set has been tuned in to a certain station, it may involve an additional mani-

pulation, viz. turning the aerial to achieve the optimum signal. A hinged frame outside the cabinet as used with the 902 A (fig. 1), was not considered acceptable, and turning the whole receiver, whilst not objectionable for a small set, would hardly do for a large one.

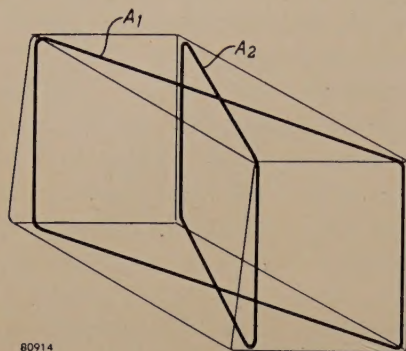


Fig. 7. Mounting of two crossed frame aerials (A_1 , A_2) in a radio cabinet.

This difficulty was solved by providing the set with *two* fixed frame aerials, arranged at a certain angle to each other (fig. 7) with a switch for switching over from one aerial to the other, so that it is a simple matter to select the frame that gives the best reception from a given station. This system is applied, for example, in the receiver type BX 430 A-10 (fig. 8).

The angle between the two frames need only be small, as will be demonstrated in the second part of this article.

Each frame consists of two turns, for the following reason. The switch contacts (for switching over from one frame to the other and from medium to long-wave reception) are incorpo-

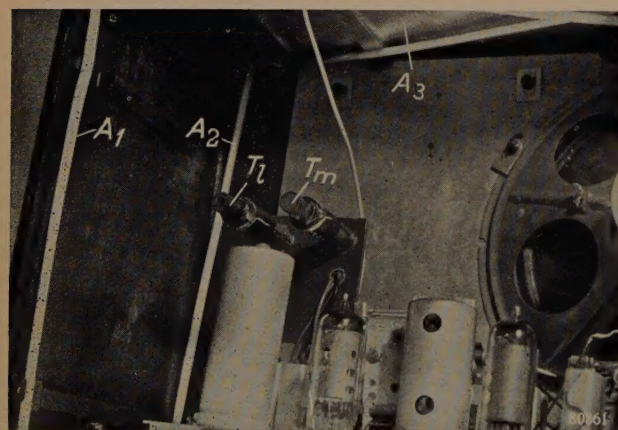


Fig. 8. Interior view of receiver BX 430 A-10. The two crossed frame aerials, (A_1 , A_2 , each consisting of two turns in this case) are partly visible. T_1 h.f. transformer for long wave reception, T_m h.f. transformer for medium wave reception, both having Ferroxcube cores. A_3 capacitive plate aerial for short wave reception.

rated in the frame circuit. The contact resistance, although as low as a few $m\Omega$ per contact, would considerably impair the quality factor of a single loop circuit; in a two-turn frame, however, with its greater self-inductance and resistance, the influence of the contact resistance may be neglected. At the same time, the sensitivity to interference is not noticeably increased.

Both the single and two-turn frames can be classified as "low impedance frame aerials", in contrast with the Ferroxcube aerials, which will now be discussed.

Ferroxcube aerials (ferroceptors)

Another type of inductive aerial in which Ferroxcube plays an even more important part than in a frame aerial of few turns, consists of a coil wound on a Ferroxcube rod. A coil diameter of 6-15 mm is sufficient, owing to the exceptionally high permeability of the Ferroxcube; the magnetic flux of a far greater area is, as it were, concentrated in the core (see fig. 9).

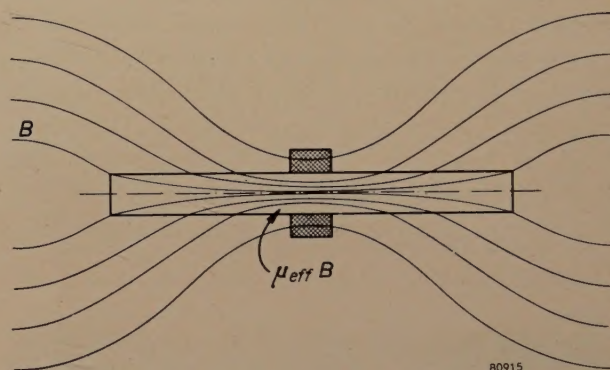


Fig. 9. A Ferroxcube rod concentrates an external magnetic field of induction B into a field of induction $\mu_{eff}B$ at the middle of the rod.

Without any intermediate transformer, the coil and the tuning capacitor constitute the first resonant circuit; the coil therefore has a far greater impedance than a frame of one or two turns. The shape of the coil no longer justifies the name of frame aerial, so the device is referred to as a Ferroxcube antenna or ferroceptor.

In Europe, Ferroxcube aerials were first manufactured on a large scale by "La Radiotechnique" of Suresnes. After meeting with great success in France they were also introduced in other countries. In the small medium/long wave Philips receiver BX 221 U-10, a single rod of Ferroxcube is used, fixed in a permanent position inside the set (fig. 10) and provided with one coil for long waves and another for medium waves. The slightly bigger set BX 321 A-10, has two fixed rods, one for long waves and one for medium waves; a capacitive plate aerial is used for short waves (fig. 11).

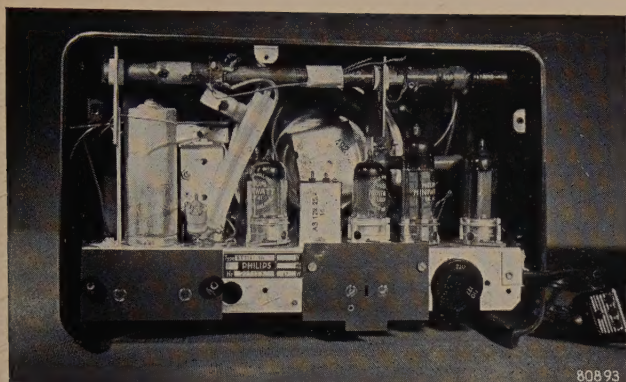


Fig. 10. Receiver BX 221 U-10, equipped with a long wave coil and a medium-wave coil on a single rod of Ferroxcube (ferroceptor).

In large sets, such as the BX 632 A and the BX 633 A, the two rods can be rotated in a horizontal plane by means of a knob (fig. 12).

The question arises as to how far the influence of the aerial-effect will be felt, in view of the fact that the coil has a fairly large number of turns. A favourable circumstance is that the dimensions of the coil are small, so that the capacitance with respect to the surroundings is small. A further reduction of capacitive reception can, if necessary, be effected by two measures: compensation of the aerial-effect and electrical screening.

Fig. 13 shows how the aerial-effect can be compensated. The interference voltage from, say, a source V_n in the mains is coupled by the capacitance C_a of the ferroceptor coil L . This voltage can be compensated by means of a second coil L' , coupled to L and having a capacitance $C_{a'}$ with respect to its surroundings; if $C_{a'}$ has the correct value, the interference current through L' is such that it induces in L a voltage which cancels the former interference voltage.

Let us assume that the number of turns of L' is p times that of L , and let k represent the coefficient of coupling between the two coils. The condition for compensation is then approximately given by

$$k = -\frac{1}{p} \cdot \frac{C_a}{C_{a'}}$$

Either k may be varied by altering the distance between the coils, or $C_{a'}$ may be varied by adjustment of an earthed plate placed in the vicinity (fig. 11).

A minor disadvantage is that the equilibrium is disturbed by any slight capacitance change, so that a hand approaching the set may cause a noticeable rise of the interference level.

In the medium wave range the interference level is so much lower that the receiver BX 321 A-10 does not require any compensation, but only a some electrical screening. This is effected by placing the

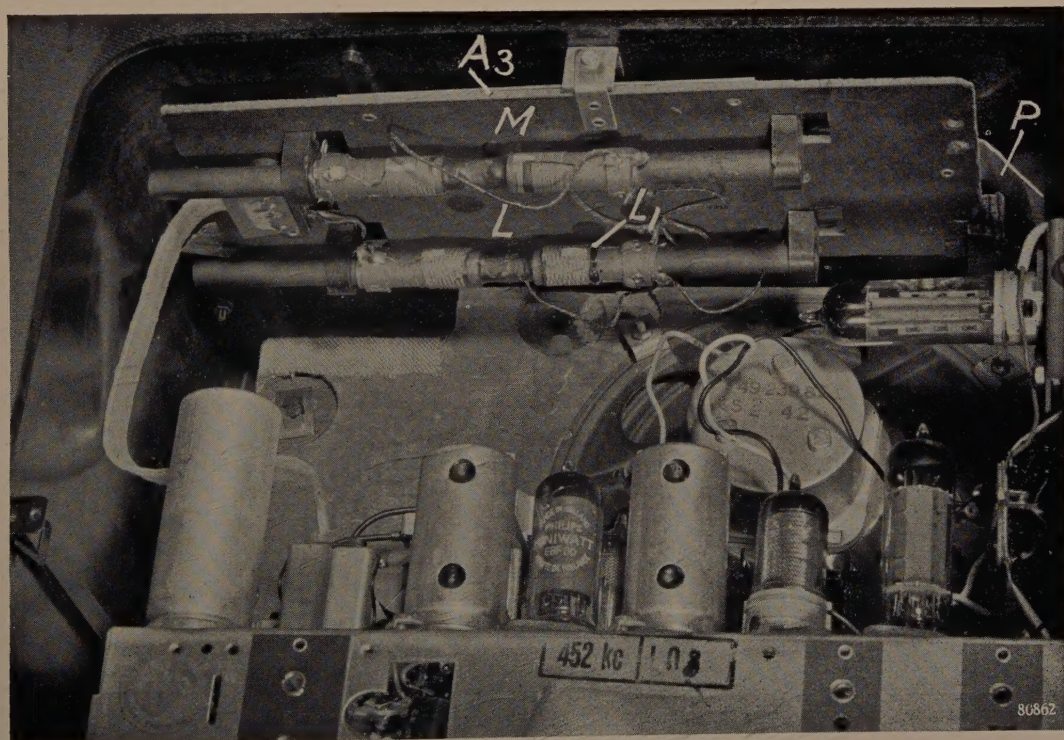


Fig. 11. The receiver BX 321 A-10 has separate Ferroxcube rods for receiving long waves (L) and medium waves (M). For long wave reception the aerial effect is compensated by means of a compensating coil L_1 and the adjustable plate P (cf. fig. 13).

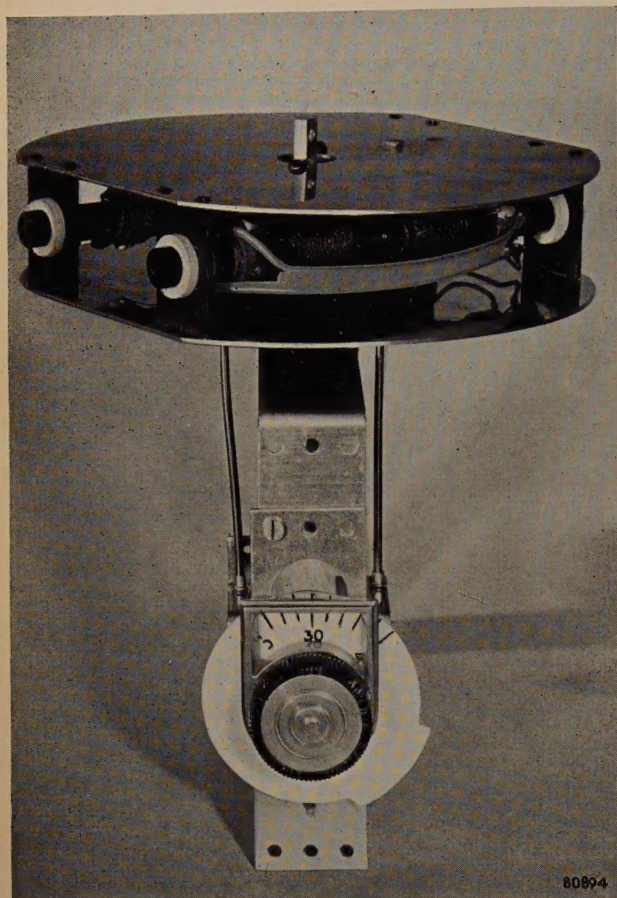


Fig. 12. Two rotatable Ferroxcube aerials (long and medium waves). Some sets (e.g. BX 632 A and 633 A) have a construction allowing the set to receive on a capacitive (outdoor) aerial in the zero position of the knob. When the knob is turned clockwise, this aerial is disconnected and the scale indicating the position of the Ferroxcube antennae lights up as a sign that reception now takes place exclusively via the Ferroxcube aerials. (In versions later than the one depicted, the scale range is more than 180° .)

II. TECHNICAL ASPECTS OF INDUCTIVE AERIALS

This section deals with the directional effect and with three factors of particular importance in design: sensitivity, signal-to-noise ratio and effective height.

The directional effect

The signal voltage induced in a frame aerial, assuming the complete absence of capacitive reception, is proportional to $\sin \alpha$, where α is the angle between the perpendicular to the plane of the loop and the direction of the transmitter. Plotting the signal voltage in a polar diagram gives the well-known figure-of-eight curve (fig. 14).

At a value of $\alpha = 30^\circ$ the voltage is reduced to half the maximum value, whilst the minima at $\alpha = 0$ are sharply defined.

ferroceptors between the chassis and the capacitive plate aerial (fig. 11); the latter is connected to the chassis during medium-wave reception. In the construction shown in fig. 12 the two rods are mounted between two earthed metal plates. Screening may be further improved by surrounding this assembly by a cage made of copper wire running parallel to the core, interwoven with nylon threads in the perpendicular direction (to avoid magnetic screening).

In contrast with the screening of ordinary frame aerials, the above-mentioned methods only slightly increase the self-capacitance, owing to the small dimensions of the coil.

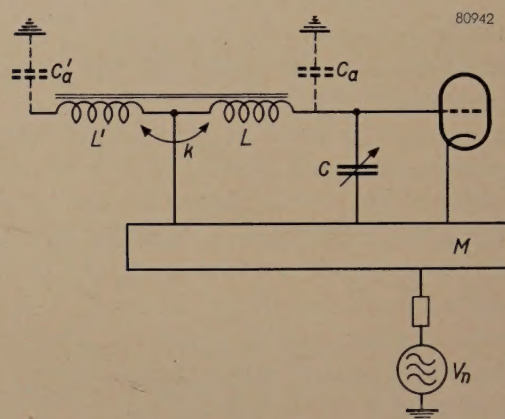


Fig. 13. Circuit for compensating the aerial-effect of a Ferroxcube aerial L . L' = compensating coil coupled with L (L_1 in fig. 11). C_a and $C_{a'}$ = capacitance of L and L' respectively with respect to the surroundings. At suitable values of $C_{a'}$ and of the coupling coefficient k , no interference voltage will be produced across the tuning capacitor C (V_n = source of interference). M = chassis.

In order to evaluate the directional effect, however, we are not so much concerned with the voltage

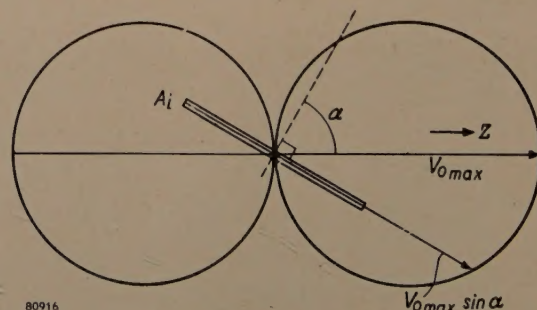


Fig. 14. The figure-of-eight polar diagram of an inductive aerial (A_i) having no capacitive component. The signal voltage in the aerial is $V_{0\max} \sin \alpha$, α being the angle between the perpendicular to the plane of the loop and the direction Z of the transmitter.

induced in the frame as with the volume produced by the loudspeaker. Let us for the moment assume that the set operates without automatic volume control. We then get a nearer representation of the volume of sound by plotting the induced voltage in polar co-ordinates on a logarithmic scale. In fig. 15, curve 1, the maximum sound volume ($\alpha = 90^\circ$) is set at a level of 0 dB. At $\alpha = 30^\circ$ the level is -6 dB, at $\alpha = 6^\circ$ it is -20 dB.

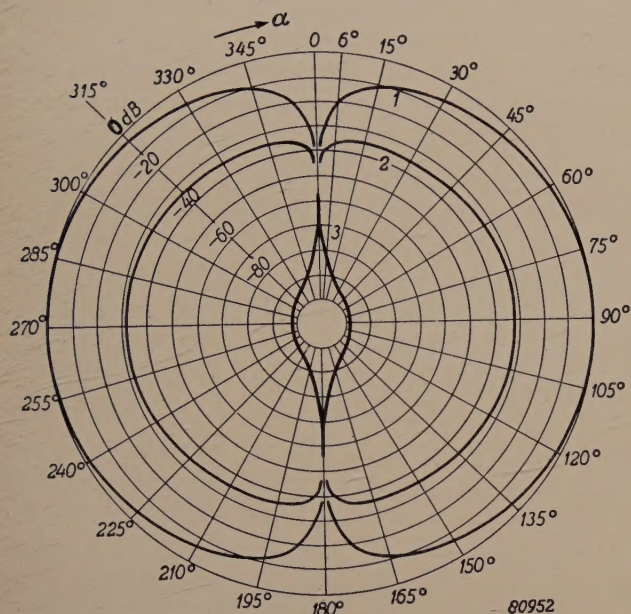


Fig. 15. 1 represents the curve of fig. 14 plotted on a decibel scale. 2 the same, taking into account the effect of the automatic volume control (cf. fig. 16). 3 level of noise and interference.

The automatic volume control should not, however, be left out of consideration. Its effect is shown in the curve in fig. 16, which can be regarded as representative for many modern receivers.

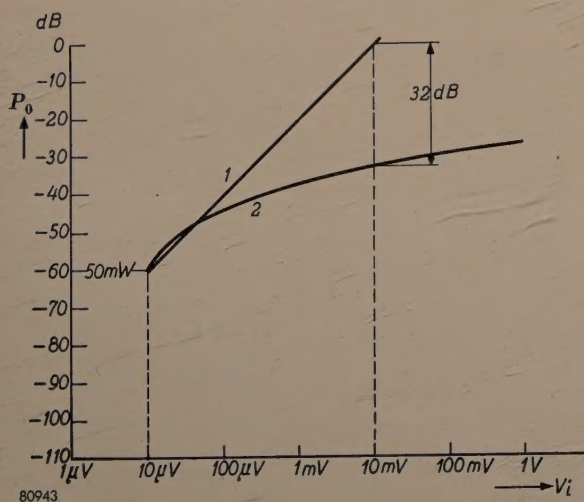


Fig. 16. Output signal P_0 of a radio receiver as a function of the input voltage V_i , 1 without a.v.c., 2 with a.v.c. At $V_i = 10$ mV the difference amounts to 32 dB. The vertical scale is made to correspond to the decibel scale of fig. 15.

Assuming a maximum input voltage ($\alpha = 90^\circ$) of 10 mV, we see that the amplification is reduced by 32 dB by the A.V.C. At $\alpha = 30^\circ$ the input voltage is 5 mV, i.e. 6 dB less than at $\alpha = 90^\circ$; the reduction in amplification is then 28 dB, so that the sound level lies only $32 - (6 + 28) = 2$ dB below the level produced at $\alpha = 90^\circ$. At $\alpha = 6^\circ$ the difference is no more than 5 dB; cf. curve 2 in fig. 15. It will now be clear that the angle between two fixed frames (cf. Part I) can be quite small, for if one frame happens to be in the position of minimum reception ($\alpha = 0^\circ$), the other gives a satisfactory signal if it crosses the former at even a small angle. Hence the two frames can lie along the diagonals of quite a flat cabinet: there is no need to make them smaller in order to include a larger angle.

Near the minimum, also the noise level has to be taken into account (under the term noise we include here also the continuous interference referred to in Part I). If it is assumed that in the position of the frame for maximum signal, the reception is just free of audible noise, then the noise level at the input is 66 dB lower than the signal level¹⁰) i.e. lower by a factor of 2000, and lies in fig. 15 at $-(66 + 32) = -98$ dB. The more α is reduced, the greater becomes the amplification by the A.V.C. and thus the absolute value of the noise increases. The result is represented by curve 3 in fig. 15. When α approaches zero the sound volume of the signal drops only slightly, but the noise increases rapidly. The best way to adjust the set for maximum reception is, therefore, by first setting the aerial for maximum noise (i.e. minimum reception) and then turning it through 90° .

Sensitivity and signal-to-noise factor

The sensitivity of a frame aerial may be defined as the signal voltage supplied by the aerial circuit to the grid of the first tube, per unit electric field strength E of the local radiation field. This grid voltage is Q times the voltage induced in the aerial (Q being the quality factor of the aerial circuit); the induced voltage is given by hE , according to the definition of the "effective height" (h) of an inductive aerial¹¹).

¹⁰) M. Ziegler, Noise in receiving sets, Philips tech. Rev. 3, 189-196, 1938, in particular, page 196.

¹¹) The effective height of an inductive aerial has obviously no concrete physical meaning, but is only a quantity introduced for mathematical reasons. It is defined as the effective height of a capacitive aerial, which, placed in the same field of radiation, would produce the same signal voltage V_0 as the inductive aerial when oriented for strongest reception. The definition of the effective height of a capacitive aerial as $h = V_0/E$ is readily acceptable.

For the sensitivity S we find, therefore:

$$S = QhE/E = Qh. \dots \dots (1)$$

We define the signal-to-noise factor N as the variable term in the signal-to-noise ratio, viz. the ratio of the signal power in the frame circuit for unit E , to the noise power in this circuit. It can be shown (see below, small print) that N is given by

$$N = Qh^2. \dots \dots (2)$$

If the field E is of unit strength, then the signal voltage V_s across the tuning capacitor is by definition S and hence

$$V_s = Qh.$$

If we introduce a parallel resistance R to account for the absorption of the signal, then this resistance will dissipate a signal power P_s given by

$$P_s = \frac{V_s^2}{R} = \frac{Q^2 h^2}{R}. \dots \dots (3)$$

The resistance R is responsible for the noise:

$$\overline{V_n^2} = 4KT\Delta fR,$$

in which $\sqrt{\overline{V_n^2}}$ = r.m.s. value of the noise voltage, K = Boltzmann's constant, T = absolute temperature of the resistance R and Δf = frequency band under consideration. The noise power P_n is then:

$$P_n = \frac{\overline{V_n^2}}{R}. \dots \dots (4)$$

From (3) and (4) we obtain for the signal-to-noise ratio:

$$\frac{P_s}{P_n} = \frac{V_s^2}{\overline{V_n^2}} = \frac{Q^2 h^2}{4KT\Delta fR}.$$

If L is the self-inductance of the circuit and $\omega = 2\pi \times$ the resonance frequency, then $Q = R/\omega L$ and $Q\omega L$ may be substituted for R :

$$\frac{P_s}{P_n} = \frac{1}{4KT\Delta f\omega L} Qh^2.$$

In the case considered here, $4KT\Delta f\omega L$ may be considered as a constant and Qh^2 is, therefore, the term which effectively determines the signal-to-noise ratio.

Both the quality factor and the induced voltage per unit of field strength can be calculated as well as measured. For a given design, therefore, both the sensitivity and the signal-to-noise factor can be calculated.

As mentioned above, Philips are currently using two types of inductive aerials: the frame aerial of low impedance (few turns) and the Ferroxcube antenna or ferroceptor. We shall now separately examine the two types with regard to sensitivity and signal-to-noise factor.

The low-impedance frame aerial

Fig. 17a shows a frame aerial of one or a few turns. It is coupled, via h.f. transformer T , to tuning capacitor C , which in turn is connected to the first amplifying tube. Self-inductances are designated

by L and resistances by r ; the indices $0, 1, 2$, refer to the frame, the primary and the secondary coil respectively. For this diagram we may substitute the equivalent circuit of fig. 17b. Assuming that the transformer is ideal, having no leakage (coupling factor $k = 1$) and no losses, and that the self-inductances L_1 and L_2 are infinite (the ratio L_2/L_1 , however, having a finite value), then

$$V = V_0 \sqrt{\frac{L_2}{L_1}}, \dots \dots (5)$$

where V represents the e.m.f. of the equivalent generator (fig. 17b) and V_0 is the e.m.f. induced in the frame (fig. 17a). Assuming no transformer losses we may put:

$$Q = Q_0 = \frac{\omega L_0}{r_0}. \dots \dots (6)$$

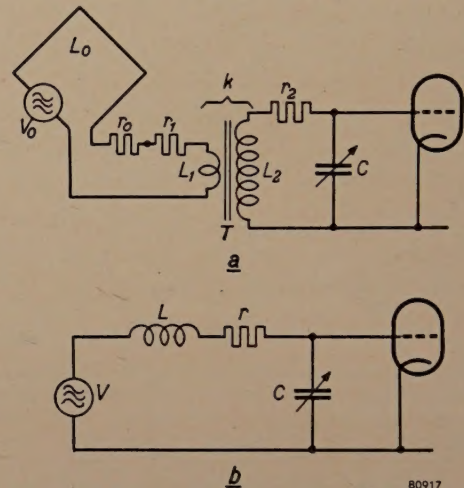


Fig. 17. a) L_0 frame aerial with low impedance, coupled to tuning capacitor C via an h.f. transformer T . The voltage induced in the frame aerial is V_0 . The resistance of the frame, of the primary coil (self-inductance L_1) and the secondary coil (self-inductance L_2) are r_0, r_1 and r_2 respectively. The coupling coefficient is k . b) Equivalent circuit of (a).

For the tuning, it is not the self-inductance L_0 of the frame but the "effective" self-inductance L (fig. 17b) which is the determining factor, since it is the latter in combination with C , which defines the frequency of resonance. It is thus more logical to take into account the effective height h of frame and h.f. transformer together than that of the aerial alone. We will define the effective height h of the combination as the value of V (not V_0) per unit field strength. For $E = 1$, equation (5) may be written as

$$h = h_0 \sqrt{\frac{L_2}{L_1}}. \dots \dots (5a)$$

(h_0 is the effective height of the frame alone, i.e. the value of V_0 at $E = 1$).

As, however, the transformer is not ideal, the formulae actually applicable are more involved, viz.:

$$h = \frac{k}{1 + \frac{L_0}{L_1}} h_0 \sqrt{\frac{L_2}{L_1}}, \quad \dots \quad (5b)$$

and

$$Q = Q_2 \frac{\left(1 + \frac{L_0}{L_1} - k^2\right) \left(1 + \frac{L_0}{L_1}\right)}{\left(1 + \frac{L_0}{L_1}\right)^2 + k^2 \left(\frac{Q_2}{Q_1} + \frac{Q_2}{Q_0} \cdot \frac{L_0}{L_1}\right)} \dots \quad (6b)$$

Here Q_1 and Q_2 are the quality factors of the primary and the secondary respectively of the transformer.

The formulae (5b) and (6b) determine h and Q , the two factors giving the sensitivity $S (= Qh)$ and the signal-to-noise factor $N (= Qh^2)$. It is generally desirable that both S and N are large. The formulae show that h and Q , at given values of Q_0 , Q_1 and Q_2 , are dependent on only two quantities: the coupling factor k and the matching ratio L_0/L_1 . As regards sensitivity and signal-to-noise factor, it is therefore immaterial how many turns the frame has. The number of turns may therefore be selected according to other criteria, e.g. the sensitivity to local interference and constructional considerations. As discussed in Part I, the sensitivity to local interference is proportional to the number of turns. For this reason the number is chosen as small as possible, preferably one, which is also convenient from the constructional point of view.

Further examination of (5b) and (6b) shows that if k is increased or the value of L_0/L_1 is reduced, h becomes greater, but Q smaller. Hence it may be expected that the Qh and Qh^2 as functions of k and of L_0/L_1 will show one or more stationary values. Analyzing Qh shows that it does indeed have a maximum at $k = 1$ and L_0/L_1 somewhere between 3 and 5, dependent on the various Q -values. Similarly Qh^2 is found to have a maximum at $k = 1$ and L_0/L_1 between 1.5 and 2.5 (likewise dependent on the Q -values). The value of k^2 can drop to approx. 0.7 before the maximum shows a substantial drop. Fig. 18 shows Qh and Qh^2 as functions of L_0/L_1 for certain practical values of k , Q_0 , Q_1 and Q_2 . Since the maxima of the two curves do not occur at the same value of L_0/L_1 , a suitable compromise value has to be sought. In this connection the following considerations should be taken into account. If the set itself contains a rather strong source of noise, there is little point in designing a frame aerial with the greatest possible signal-to-noise factor (Qh^2); in that case it is better to strive

for maximum sensitivity (Qh). For a receiver having very little inherent noise it is preferable to design a frame aerial producing the least possible noise, if necessary by sacrificing a little of the sensitivity.

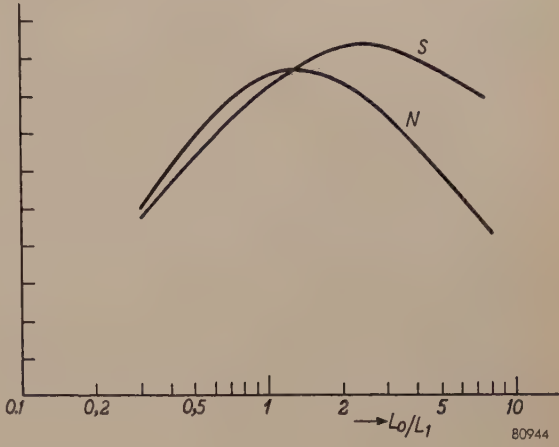


Fig. 18. Sensitivity $S = Qh$ and signal-to-noise factor $N = Qh^2$ plotted as functions of L_0/L_1 , for $k^2 = 0.70$ and $Q_0 = Q_1 = Q_2$.

The Ferroxcube antenna (ferroceptor)

Consider a Ferroxcube rod (length l , diameter d , fig. 19), on which is wound a flat coil (width $a < d$; at a distance x from the middle). Fig. 19 also shows a measured curve of the effective relative permeability $\mu_x = B_x/H$, plotted as a function of x (B_x being the magnetic induction at position x due to the transmitter field H). For fairly small values of l/d this curve approximates to a parabola, which can be represented by

$$\mu_x = \mu_{\text{eff}} \left(1 - 3.6 \frac{x^2}{l^2}\right).$$

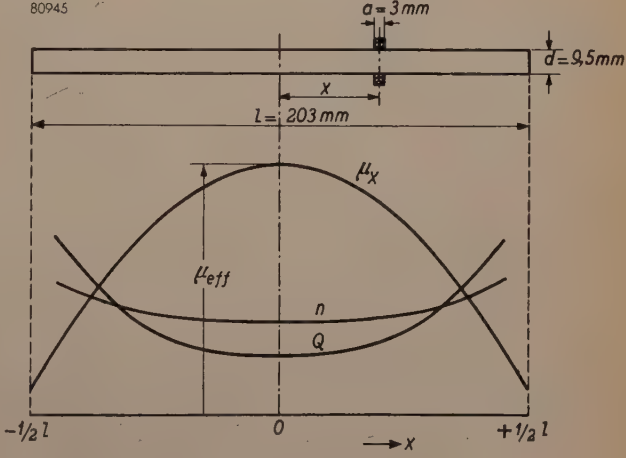


Fig. 19. Above: Ferroxcube rod of length l with flat coil, placed at a distance x from the mid-point. The curves represent μ_x , Q and n as functions of x , for a rod of Ferroxcube IV-B of the dimensions shown, wound with a coil of width $a = 3$ mm and a self-inductance of $200 \mu\text{H}$ at 1 Mc/s .

μ_{eff} , the maximum value of μ_x , determines the extent to which the Ferroxcube concentrates the transmitter field in the core. μ_{eff} depends on l/d and on the toroid permeability μ_{tor} of the material (i.e. the relative permeability measured on a closed toroid, see fig. 20¹²⁾.

Fig. 19 also shows the number of turns n required for a coil of given self-inductance, and the quality factor Q of such a coil at a given frequency.

For the effective height h , the formula

$$h = \frac{2\pi\mu_x n A}{\lambda}, \dots\dots\dots (7)$$

applies, A being the area of a turn and λ the wavelength.

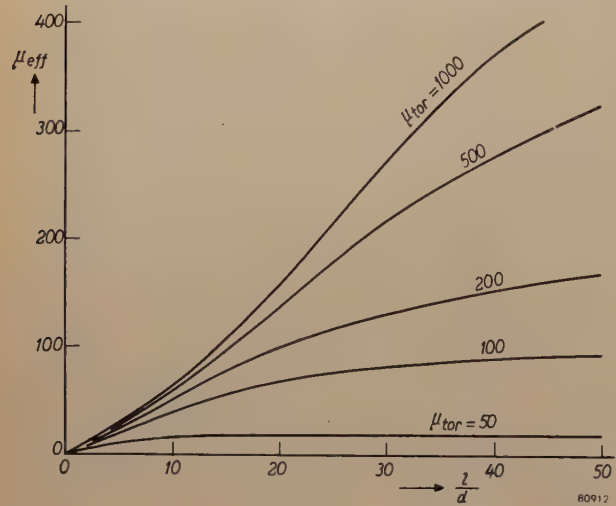


Fig. 20. μ_{eff} (the maximum value of μ_x) as a function of l/d , for various values of μ_{tor} .

Equation (7) is derived as follows: The transmitter field H induces in the coil an e.m.f. given by:

$$V = nA\omega B_x = nA\omega\mu_x\mu_0 H \dots\dots\dots (8)$$

(μ_0 = permeability of free space). Now, ω may be written as $2\pi c/\lambda$, and in a radiation field $H = E/\mu_0 c$. Substituting, (8) becomes

$$V = \frac{2\pi\mu_x n A}{\lambda} E. \dots\dots\dots (9)$$

By definition $h = V/E$. Substituting hE for V in (9) we arrive at (7), the required result.

Using (7), we find for the sensitivity:

$$S = Qh = \frac{2\pi}{\lambda} \mu_x n Q$$

and for the signal-to-noise factor:

$$N = Qh^2 = \frac{4\pi^2}{\lambda^2} \mu_x^2 n^2 Q.$$

¹²⁾ For further details see H. van Suchtelen, Ferroxcube aerial rods, Electronic Applications Bulletin 13, 88-100, 1952.

where μ_x , n and Q are the functions of x shown in fig. 19. With the help off these curves we can plot S and N as functions of x . This is shown in fig. 21,

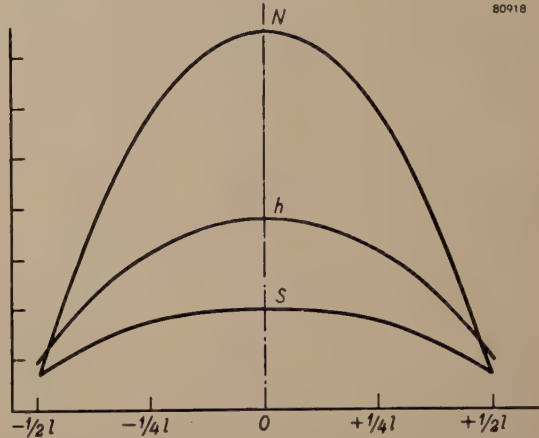


Fig. 21. S , N and h as functions of x for a narrow coil (cf fig. 19).

which also shows the curve for h . It can be seen that in the middle of the rod the sensitivity has a very flat maximum, whilst the signal-to-noise factor shows a fairly sharp maximum. This applies to a rod with a flat coil. As a further variable the coil *width* a may now be introduced. Both graphical analysis and actual experiments indicate that the optimum design is a coil of width $l/2$ situated in the middle of the rod (fig. 22). In practice, however, this construction cannot always be used for the following reasons:

- 1) The self-inductance should be adjustable, but near the middle of the rod a shifting of the coil has little effect. If one can indulge in the luxury of two Ferroxcube rods (one for long and one for medium waves), then either a small trimming coil may be added at the end of the rod, or the coil may be divided into two parts, situated a small distance apart on either side of the middle of the rod; the self-inductance is then adjustable by varying the degree of coupling between the two parts of the coil. e.g. by changing their separation.
- 2) In some cases considerations of price make it necessary to combine the medium and the long wave coil on a single rod (fig. 23). This presents some difficulties for the reception of medium

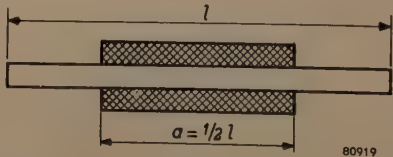


Fig. 22. The optimum shape for a ferroceptor coil is a "width" a equal to half the length l of the ferroxcube rod.

waves. If the long-wave coil remains open-circuited, its self-capacitance constitutes an absorption circuit for medium waves and thus introduces certain losses. There are two ways for avoiding this drawback:

- The long-wave coil is short-circuited during the reception of medium waves. This has the disadvantage that a length b of the rod (fig. 23) is rendered useless, since the short-circuited coil prevents a field occurring in part b , particularly if the coil has a high quality factor. For the remaining part of the Ferroxcube rod the value of l/d is smaller, and consequently μ_{eff} and h are also smaller (see next section).
- The long-wave coil is connected in parallel with the medium-wave coil during the reception of medium waves. The apparent shortening of the rod does not then occur (the effective height of the combination is even slightly greater than that of the medium wave coil alone). The fact, however, that parallel connection increases the self-capacitance considerably, often proves an insuperable drawback, and one has to resort to short-circuiting the long-wave coil as mentioned in (a).

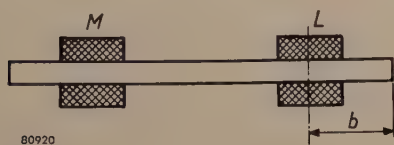


Fig. 23. Medium wave coil M and long wave coil L wound on a single rod of Ferroxcube. When, for medium wave reception, the long wave coil is short-circuited, part b of the rod becomes ineffective.

Effective height and rod dimensions of a Ferroxcube antenna

The effective height of a coil situated in the middle of the rod is proportional to $l/\sqrt{d}$. This can be derived as follows.

The self-inductance L of the coil is proportional to n^2d , i.e.

$$n \propto \sqrt{L/d} \quad (10)$$

According to fig. 20, for not too large values of l/d , we have

$$\mu_{\text{eff}} \propto l/d \quad (11)$$

By applying (10) and (11) to equation (8), and putting $\mu_x = \mu_{\text{eff}}$ (since the coil is in the middle of the rod), we find that the e.m.f. induced in the coil, and hence also the effective height, is proportional to $l/\sqrt{d}$.

From the fact that h is proportional to $l/\sqrt{d}$ it is clear that the length l of the rod should be chosen

as large as possible. When this length has been decided upon (as a rule determined by the width of the cabinet, or, for rotatable rods, by its depth), the thickness of the rod must be decided. Considering a constant length, the fact that h is proportional to $\sqrt{d}$ means that h increases only as the fourth root of the volume: in order to double h by using a thicker rod, 16 times as much Ferroxcube is required!

It will be obvious that the ratio l/d should be chosen as large as possible, having regard, however, to the magnetic and mechanical properties of the material. For Ferroxcube IV-D, e.g., with $\mu_{\text{tor}} = 40$, there is no point in choosing l/d greater than 15, since at greater values there is hardly any increase of μ_{eff} (fig. 20). For the materials with greater toroid permeability (Ferroxcube IV-B, $\mu_{\text{tor}} = 200$ and Ferroxcube III-B, $\mu_{\text{tor}} = 700$) l/d cannot be raised much above 25 in view of their brittleness.

Other points to consider are the core losses and the temperature coefficient of the permeability. As regards the core losses, Ferroxcube IV-B can be used up to higher frequencies than Ferroxcube III-B, but the latter has a smaller temperature coefficient. For rods exclusively intended for medium wave reception Ferroxcube IV-B is generally used, and for long wave reception mostly Ferroxcube III-B. If medium and long-wave coils are to be situated on a single rod (fig. 23), then either the whole rod is made of Ferroxcube IV-B, or the medium wave part is made of Ferroxcube IV-B and the long wave part of Ferroxcube III-B. The latter construction is shown in fig. 10; the Ferroxcube III-B part, whose permeability has the smallest temperature coefficient, is situated above the tubes, where most heat is generated.

Finally a commonly applied method for obtaining a greater effective height for a given volume of Ferroxcube may be mentioned. This consists of using a number p of parallel, identical Ferroxcube rods, each provided with a small coil (fig. 24). The coils are connected in series and the rods are spaced so far apart that there is little mutual interaction

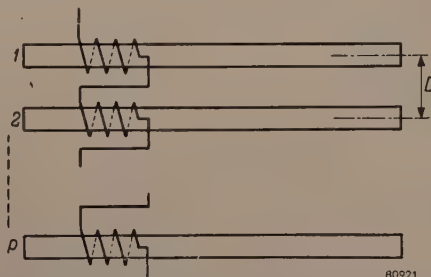


Fig. 24. Ferroxcube aerial consisting of p parallel Ferroxcube rods, each wound with one coil. The coils are connected in series.

between the coils (separation $D \geq d\sqrt{\mu_{\text{eff}}}$, e.g. 8 cm).

For a total self-inductance L , the self-inductance per coil must be L/p . If n_1 turns are required for one coil with a self-inductance L , then for p coils with the same total inductance $p^{-\frac{1}{2}}n_1$ turns are required per coil. In total this corresponds to $p \cdot p^{-\frac{1}{2}}n_1 = p^{\frac{1}{2}}n_1$ turns linking the field. The voltage induced is therefore p times as great as in the case of a single rod (n_1 turns). Since the effective height h is defined as the voltage induced per unit field, we have $h \propto p^{\frac{1}{2}}$. The volume of Ferroxcube used is proportional to p , the number of rods used (l and d being constants); hence the effective height is proportional to the *square root* of this volume. This is more favourable than the *fourth root* relationship applying to a single rod. The application of a number of parallel rods thus produces a greater effective height or a saving

in Ferroxcube. For practical reasons more than two rods are seldom used.

Summary. As early as 1939 Philips marketed a radio receiver (type 902 A) equipped with a single-loop frame aerial. This design was based on the fact that an inductive aerial is less sensitive to local interference than a capacitative aerial, and that the aerial-effect of an inductive aerial is diminished by reducing the number of turns. Until the introduction of Ferroxcube, however, frame aerials with few turns were not used on a large scale. Ferroxcube enables the dimensions of the h.f. transformer coupling the aerial loop to the tuning capacitor to be drastically reduced. A number of Philips sets employ two such frame aerials, set at a small angle to each other, for both medium and long wave reception; by means of a switch, the loop giving the most satisfactory reception of a certain station can be selected. Short waves are received by a capacitative plate aerial. Another form of inductive aerial is the Ferroxcube antenna or ferroceptor, consisting of a coil wound on a Ferroxcube rod. Various designs are dealt with. Part I of this article gives a brief history and a general description of these inductive aerials. The second part of the article examines in closer detail the directional effect, the sensitivity, the signal-to-noise factor and the effective height.

THE DIFFERENT TELEVISION STANDARDS CONSIDERED FROM THE POINT OF VIEW OF RECEIVER DESIGN

by W. WERNER.

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The diversity of European television standards has been referred to more than once in this Review. From the point of view of those concerned with T.V. transmission, the most important consequence of this lack of uniformity is that it necessitates the use of "line converters" in any international exchange of programmes. The receiver designer, on the other hand, is concerned with the demand created in certain regions for sets able to operate in accordance with two or more different standards. Examples of such regions are the Saar, the districts along the Franco-German border, and, above all, Belgium. In Belgium two different standards are employed, one for Walloon, and one for Flemish transmissions; moreover, both these standards differ from those of the surrounding countries, i.e. France on the one side and Holland and Germany on the other.

As an introduction to an article on a four-standard receiver specially designed for Belgium, to be published in due course, the different regional standards and a number of associated problems will now be discussed.

A number of different standards for black and white (or "monochromatic") television are at present in force. Several European countries (including the Netherlands and West Germany), and also one or two countries outside Europe, have adopted what is known as the Gerber standard ¹⁾, a 625-line system. Before this standard was accepted by the Comité Consultatif International des Radiocommunications (C.C.I.R.) (October 1950), an experimental transmitter designed by Philips to a standard having much in common with the American system was operated at Eindhoven. (The Philips transmitter differed in respect of the number of lines (567) and the numbers of complete pictures per second (25); the American system uses 525 lines and 30 pictures per second.)

Articles describing a TV receiver for the 567-line system ²⁾ appeared in this Review, and in another publication, in 1948.

Table I. Characteristics of the principal television standards now in force. N = number of lines per picture, f_r = frame frequency ($\frac{1}{2} f_r$ = number of complete pictures per second), Δf = width of channel, f_s = frequency of sound carrier, f_v = frequency of vision carrier, A.M. = amplitude modulation, F.M. = frequency modulation.

Standard	N	$\frac{1}{2} f_r$ c/s	Δf Mc/s	$f_s - f_v$ Mc/s	Pict. mod.	Sound mod.
U.S.A.	525	30	6	4.5	neg.	F.M.
Great Britain	405	25	5	3.5	pos.	A.M.
France	819	25	13.15	11.15	pos.	A.M.
"Gerber" (C.C.I.R.)	625	25	7	5.5	neg.	F.M.
Belgium	819	25	7	5.5	pos.	A.M.
	625	25	7	5.5	pos.	A.M.

In Table I some characteristics of the major television standards are listed. Certain consequences of these characteristics which are of particular interest to the designer of TV receivers will now be examined. The channel-width, method of picture-modulation, and system of sound-modulation will be discussed.

Channel-width

The following features are common to all the different standards.

- a) Amplitude modulation and vestigial side-band transmission are employed for the video signal (fig. 1).
- b) The ratio between width and height of the picture is 4:3.
- c) Scanning is interlaced in an odd-even pattern.
- d) The number of complete pictures per second is 25 (except in the American system, where it is 30, so as to enable the frame frequency to be synchronized with the mains frequency, which is 60 c/s in America).

It will be seen from table I that in general the channel-width increases with the number of lines. The necessity for this may be seen as follows. The greater the number of lines employed, the higher the vertical definition of the picture. Logically, then, the horizontal definition should increase in the same proportion. Accordingly, the number of elements into which the picture is resolved during scanning increases as the square of the number of lines. The information contained in the video signal is proportional to the number of picture elements, and

¹⁾ So named after the Chairman of the C.C.I.R. sub-committee which proposed this standard; see Standards for the international 625-line black and white television system, C.C.I.R. Geneva, 10 October 1950.

²⁾ P. M. van Alphen, J. de Gier, J. Haantjes, F. Kerkhof, H. Rinia and G. J. Siezen, Home projection television, Proc. Inst. Rad. Engrs. **36**, 395-411, 1948; Projection-television receiver, Philips tech. Rev. **10**, 69-78, 97-104, 125-134, 307-317 and 364-370, 1948/49.

the bandwidth should be proportional to this information.

However, the table shows that this general rule is not invariably followed. Whereas the French standard of 819 lines specifies a channel-width of 13.15 Mc/s, according to the Belgian standard for Walloon transmissions (likewise 819 lines) 7 Mc/s is

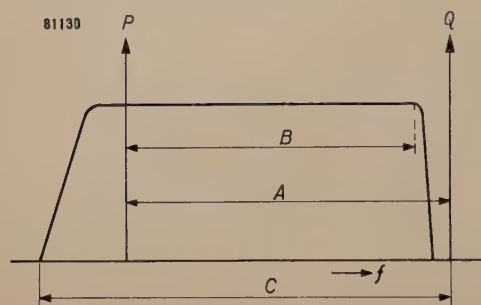


Fig. 1. Frequency spectrum of a television transmitter with asymmetrical side band ("vestigial side band"). f frequency, P vision carrier, Q sound carrier, A frequency-interval between the two, B bandwidth of complete side band transmitted, C channel width.

sufficient. Thus, in this Belgian system, some of the picture information is sacrificed for the sake of economy of channel-width.

As will be seen from fig. 1, and from the table, the frequency-interval between the vision and sound carriers should increase with the bandwidth.

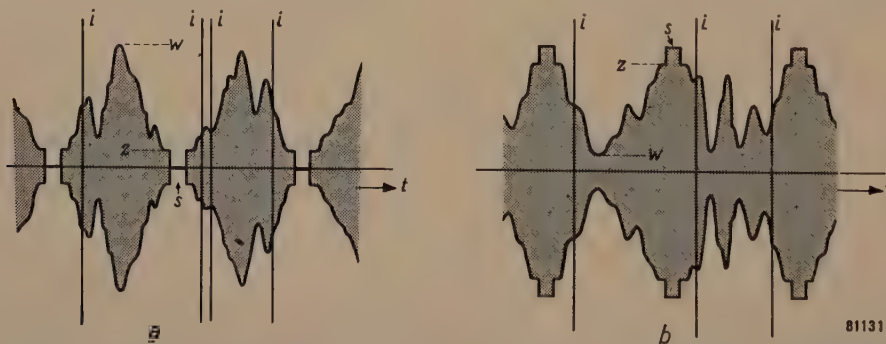


Fig. 2. Vision carrier amplitude as a function of time t , a) with positive modulation, b) with negative modulation. w level corresponding to white in the picture, z black level, s synchronizing pulses, i interference pulses.

Video modulation system

In principle, the amplitude of the vision carrier can be varied by the video signal in two ways, i.e. by positive or negative modulation (figures 2a and 2b, respectively). Peak R.F. amplitude corresponds to "white" in the picture in the case of positive modulation and to "blacker-than-black" in that of negative modulation.

The direction of the modulation determines the measures by which interference from such sources as sparking commutator motors and car ignition

systems may best be suppressed in the receiver. Such interference is in the form of pulses which, in unfavourable circumstances, may attain an amplitude far exceeding the peak value of the carrier. Interfering pulses of this type are shown at the points i in fig. 2a and 2b.

Visible interference in the form of spots

Pulse-shaped interfering signals appear on the picture as spots, which are mainly white when positive modulation is employed, and mainly black with negative modulation.

The luminance of the white spots associated with positive modulation may greatly exceed that of the brightest parts of the picture itself. If the particular interfering pulses are strong enough to drive the picture tube into grid current, the electron beam will fail to focus sharply, and the white spots will grow into bright discs. To avoid this, receivers for positive modulation are often fitted with limiters; such limiters are included in the circuit preceding the picture tube, to cut off any interference above a given level. In some cases, the cut-off level is variable.

As mentioned above, in the case of negative modulation, the spots produced by interfering pulses are mainly black. Occasional white spots also occur, but, provided that the "white" corresponds to

nearly zero modulation of the carrier, they cannot become very much brighter than the brightest parts of the picture itself (fig. 2b).

Effect of interference on synchronization

The horizontal and vertical deflection of the electron beam is synchronized by special signals included in the envelope of the transmitted television signal. Line synchronizing signals, for example, are rectangular pulses (fig. 2), whose steep leading edges initiate the flyback of the beam.

The interfering signals are likewise steep-sided; hence, of course, they are quite capable of disorganizing the synchronization completely, and thus mutilating the picture beyond recognition. Experience has shown that this is far more likely to happen when negative, than when positive, modulation is employed, owing to the fact that in negative modulation the interference pulses are predominantly in the same direction as the sync. signals, whereas in positive modulation it is the opposite. Accordingly, measures to minimize the effect of interfering pulses in the sync. circuit are particularly necessary in receivers designed for negative modulation, where the amplitude of such pulses may greatly exceed that of the sync. pulses. Such measures include the use of:

- a) a so-called "flywheel circuit" for horizontal deflection;
- b) an integrating circuit for vertical deflection;
- c) a noise-inverter circuit, to act upon the synchronizing signals before they are separated.

The flywheel method of synchronization has been described in detail in an earlier issue of this Review³⁾ and need not be discussed here. However, it is worth mentioning that in some cases this method is also employed in conjunction with positive modulation, for the following reason. A weak incoming signal is invariably associated with a relatively high noise level, which makes the edges of the sync. pulses irregular and vague. This upsets the timing of the electron beam in the picture tube, so that it starts to scan some of the lines at the wrong moment. The result is a horizontal displacement of the scanning lines relative to one another and "tearing" at the vertical sides of the picture, and at the vertical edges of individual objects in the picture. This "frayed" effect can be avoided by employing a flywheel circuit for horizontal deflection.

For the vertical deflection, an integrating circuit inserted between the sync. pulse separator and the saw-tooth generator is recommended, because pulses of short duration contribute virtually nothing to the output voltage of such a network, and are therefore unlikely to affect the frame synchronization.

In TV transmitters with negative modulation, the frame-synchronizing signal is preceded by so-called equalizing pulses⁴⁾, whose function is to help to maintain the interlacing when an integrating circuit is used. Equalizing pulses are not transmitted in the British system (positive modulation), but integrating networks are nevertheless used in some British-made receivers to stabilize the frame synchronization during periods of heavy interference.

As already mentioned, the synchronization of negative modulation systems is in principle more sensitive to interference than that of systems in which positive modulation is employed. However, it is possible to remove this disadvantage of negative modulation by providing the receiver with a noise-inverter circuit; this changes the sign of those interfering pulses which extend above a certain critical signal-level. After passing through the video amplifier, the signal voltage is fed both to the picture tube direct and to the sync. separator via the noise inverter. Hence the signal and the interference pulses must pass through the latter to reach the sync. separator.

The above-mentioned critical level is established as accurately as possible at a value just above the peaks of the sync. signals. As regards synchronization, the negative modulation system then has all the favourable characteristics of positive modulation.

The amplified video signal is, of course, applied direct to the picture tube, by-passing the inverter circuit, so as to preserve what is really the most favourable feature of negative modulation, i.e. that the spots produced in the picture by interference pulses are mainly dark and quite small.

Effect of interference on automatic gain control

Television sets designed to receive signals on more than one channel are preferably equipped with A.G.C., that is, a system controlling the amplification of the receiver in such a way that the strength of the output signal is virtually unaffected by variations in the strength of the input signal.

The most suitable measure of signal strength is a particular level of the television signal not governed by the gradation of the picture. In the case of negative modulation, then, the peak of the synchronizing pulses is the obvious choice. In principle, a D.C. voltage extracted from the input signal of the video detector by means of a simple peak-voltage rectifier could be employed as a control voltage for the vision amplifier, but in practice this simple arrangement is rendered completely ineffective by strong interference, owing to the fact that the rectifier then responds to the relatively higher peaks of the interfering pulses rather than to those of the sync. pulses. This causes an undue decrease in amplification, which may even be sufficient to fade out the picture altogether. To avoid this, a gate valve is included in some circuits. The control grid of this valve is so biased as to pass current only during the sync. pulses. Any interference occurring in the intervals between sync. pulses is then entirely

³⁾ P. A. Neeteson, Philips tech. Rev. **13**, 312-322, 1951/52.

⁴⁾ See fig. 1 in the article referred to in note ³⁾.

innocuous. Provided that the rectifier has a fairly low time constant (i.e. smaller than approx. $5 \times$ the line period), the effect on the control voltage of any interference happening to coincide with the sync. pulses will be negligible.

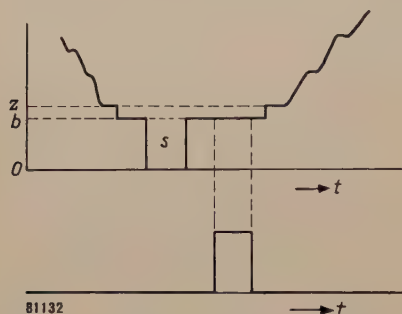


Fig. 3. Above: Vision signal with positive modulation, in the region of a line-synchronizing pulse (*s*). *z* black level, *b* blanking level.

Below: Keying pulse to operate the A.G.C. valve within the period of the blanking signal.

In the case of positive modulation, the level of the blanking signal (fig. 3), that is, the signal immediately preceding and following each sync. pulse to conceal the flyback of the scanning spot in the picture tube, may be employed as a reference level independent of picture gradation. The control voltage is extracted from this level by means of a gate valve operated intermittently by the successive

Sound modulation

Frequency-modulated systems

Frequency modulation of the sound signal in a television system offers certain advantages as compared with amplitude modulation. Firstly, we have the well-known advantage of frequency modulation in general, that is, the relatively small amount of noise and interference involved. To this may be added, in the case of television, that frequency modulation enables the receiver to be so designed that the tuning is relatively less critical, so that a certain amount of frequency drift in the local oscillator is allowable and that microphony of the oscillator is inaudible.

The particular television system employed to ensure these advantages is known as the "inter-carrier sound" system; the principle of this system may be explained with the aid of the block diagram shown in fig. 4. As will be seen from this diagram, the sound signal in the stages up to and including the video detector (D_{vid}) is amplified by the same R.F. and I.F. amplifiers as the vision signal. The mixing of these two signals produces at the output of the video detector a signal — the "intercarrier signal" — whose average frequency f_i is equal to the difference between the frequencies of the sound and vision carriers, that is, 5.5 Mc/s according to the Gerber standard, and 4.5 Mc/s according to the American system (Table I).

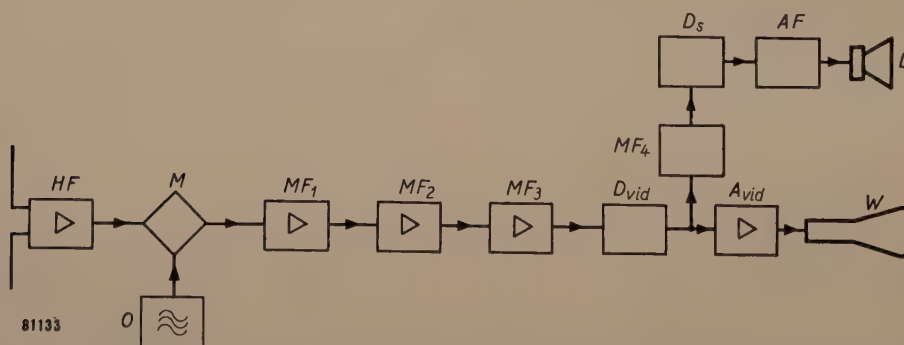


Fig. 4. Block diagram of a television receiver incorporating intercarrier sound. *HF* radio-frequency amplifier, *M* mixer stage, *O* local oscillator, *MF*₁, *MF*₂ and *MF*₃ first, second and third intermediate-frequency amplifier stages for vision and sound; *D*_{vid} video detector, *A*_{vid} video amplifier, *W* picture tube; *MF*₄ intermediate-frequency amplifier stage of sound channel (I.F. 5.5 Mc/s), *D*_s frequency detector of sound channel, *AF* audio-frequency amplifier, *L* loudspeaker.

line-synchronizing pulses. Since these pulses precede the blanking signals, they must be displaced slightly in time by means of a delay network. As in the case of negative modulation, interference other than that coinciding with the keying pulses cannot affect the control voltage.

This intercarrier signal varies in frequency with the sound modulation and in amplitude with the video modulation, since the sound and video signals applied simultaneously to the vision detector are respectively frequency-modulated, and amplitude-modulated.

The intercarrier signal passes via an amplifying stage (MF_4) to a frequency detector (D_s), which produces the audio signal and at the same time suppresses the (unwanted) amplitude modulation. A suitable rejection filter in the video amplifier (A_{vid}) prevents the intercarrier signal from reaching the picture tube and so interfering with the picture.

Television receivers are invariably tuned entirely by sound, this being far more critical than tuning to the vision signal since the sound channel covers a much narrower band. Receivers without intercarrier sound are especially critical in this respect by reason of the fact that the difference of the local oscillator frequency and the average frequency of the sound carrier must lie within the relatively narrow band (about 100 kc/s) covered by the particular I.F. amplifier in the sound channel. In receivers with intercarrier sound, on the other hand, the average frequency of the intercarrier signal (f_i) is fixed (5.5 or 4.5 Mc/s), regardless of the oscillator frequency; hence it is possible to detune the oscillator appreciably (e.g. 500 kc/s) without losing the sound. Naturally, such a receiver exhibits a similar insensitivity to deviations from the correct oscillator frequency arising from causes other than deliberate detuning, e.g. frequency drift produced by temperature variations in the local oscillator, or frequency modulation by microphony in the oscillator valve.

Against the above-mentioned advantages of intercarrier detection we must set certain disadvantages, some of which, however, can be avoided. For example, if the percentage modulation of the vision carrier is very high, the amplitude of this carrier corresponding to white in the picture will be very low; the same applies to the amplitude of the intercarrier signal. In the extreme case, i.e. 100% modulation, the intercarrier signal disappears during the scanning of white areas; hence the frequency detector has no signal to detect and the sound is temporarily interrupted. This interruption causes a highly irritating buzz (if the entire picture area be white, the television signal in the case of 100% modulation will consist solely of sync. pulses, and the frequency of the buzz will be the same as that of the frame-sync. pulses). It is prescribed, however, that the amplitude of the vision carrier may in no circumstances be less than a given fraction, e.g. 10%, of the maximum amplitude occurring during the sync. pulses (fig. 2*b*). Hence the above-mentioned buzzing noise can be avoided provided that the transmitting station complies with this standard, and that the receiver satisfies the two conditions which will now be defined. Firstly, the receiver must be so designed that even

at the maximum depth of modulation the intercarrier signal is strong enough to ensure proper operation of the frequency detector. Secondly, the selectivity of that part of the receiver preceding the video detector must be such as to ensure that the amplification of the sound signal will invariably remain roughly 10 times (that is, about 20 dB) lower than that of the vision signal (fig. 5). (The

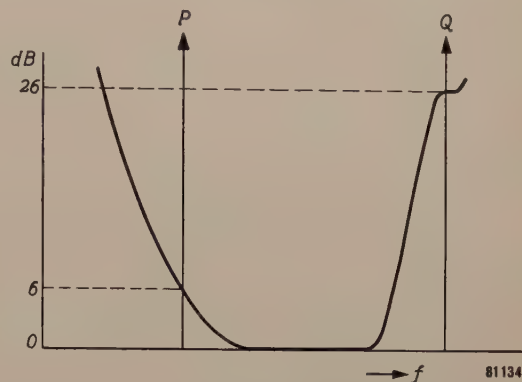


Fig. 5. Selectivity characteristic of a television receiver incorporating intercarrier sound. The input signal required to produce a given output signal is plotted logarithmically as a function of the frequency. *P* vision carrier, *Q* sound carrier. The amplification in the sound channel should be about 20 dB lower than that in the vision channel.

ratio required also depends on the strength-ratio of the vision and sound signals at the aerial terminals of the receiver, and on the extent to which the amplitude modulation is suppressed by the frequency detector.)

Unlike the above-mentioned intercarrier buzz, there is another disadvantage of intercarrier sound which cannot be avoided. This is the fact that failure of the picture transmitter is invariably accompanied by the total elimination of sound, so that any announcement concerning such a failure broadcast from the transmitting station is not heard by viewers whose sets are equipped for intercarrier detection. However, this is a minor drawback as compared with the advantages of the system. The intercarrier system is therefore employed in all Philips television receivers for TV systems with frequency-modulated sound.

Amplitude-modulated systems

Intercarrier sound is not applicable to systems with an amplitude-modulated audio channel owing to the fact that the intercarrier signal would here vary in amplitude with the sound as well as with the vision signal, thus preventing any separation of the two modulations. Fig. 6 shows the method of detection employed in conjunction with amplitude-modulated sound. The mixer valve (*M*) produces an I.F. vision signal and an I.F. sound signal; the sound signal is amplified by a separate

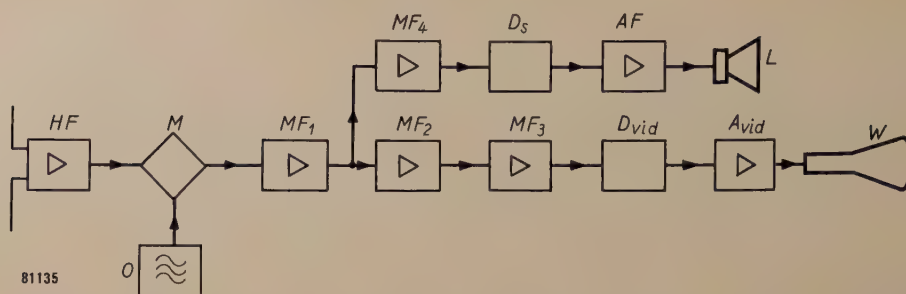


Fig. 6. Block diagram of a receiver for television systems with amplitude-modulated sound. *HF* radio-frequency amplifier stage, *M* mixer stage, *O* local oscillator, *MF*₁ first intermediate-frequency amplifier stage, for both vision and sound; *MF*₂ second and *MF*₃ third intermediate-frequency amplifier stages, for vision alone, *D*_{vid} video detector, *A*_{vid} video amplifier, *W* picture tube; *MF*₄ intermediate-frequency amplifier for sound, *D*_s amplitude detector for sound, *AF* audio-frequency amplifier, *L* loudspeaker.

I.F. amplifier (*MF*₄) and detected by an amplitude detector (*D*_s). In most cases, however, the first I.F. valve (*MF*₁) can be used to amplify both signals, without interference from cross-modulation; the

Detuning by one or two hundred kc/s is enough to eliminate the sound; hence steps must be taken to avoid frequency drift and microphony in the local oscillator.

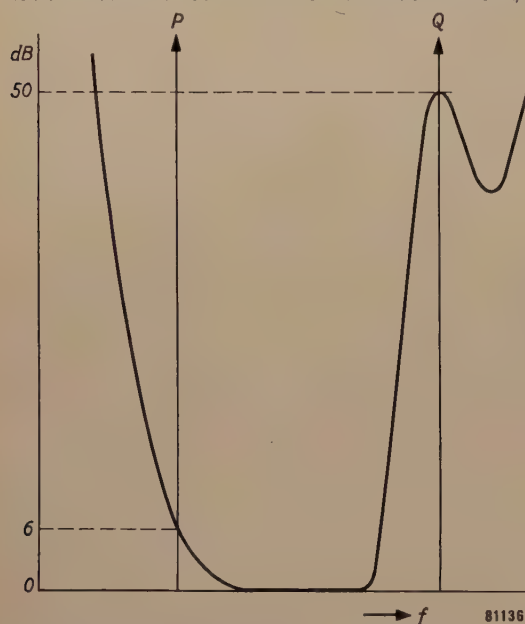


Fig. 7. Selectivity characteristic of the circuit up to the video detector in a TV receiver using A.M. sound. The amplification in the sound channel should be about 44 dB lower than that in the vision channel.

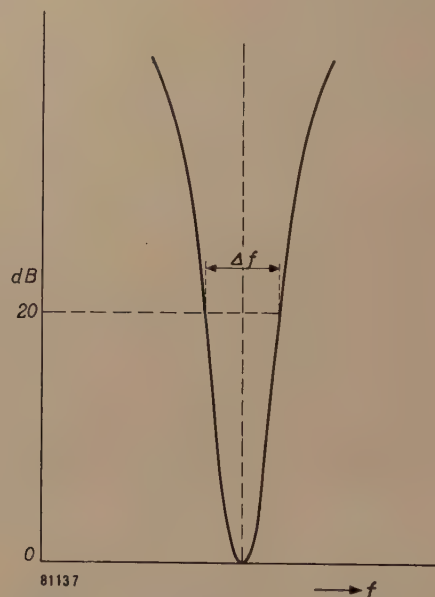


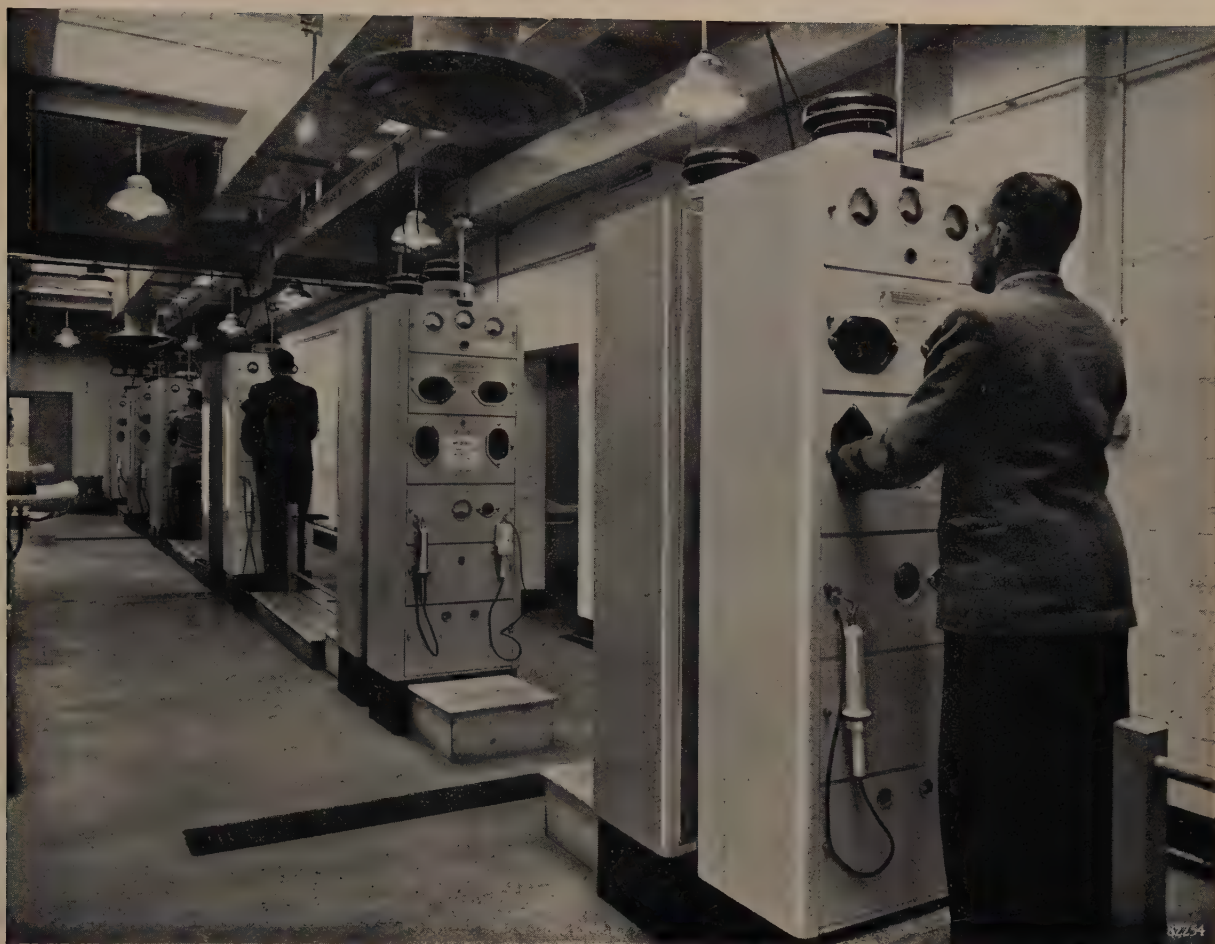
Fig. 8. Selectivity characteristic of the circuit up to the audio detector in a TV receiver using A.M. sound. At 20 dB the width Δf is about 300 kc/s.

subsequent I.F. stages for amplification of the vision signal (*MF*₂ and *MF*₃) must then include filters to adequately suppress the I.F. sound signal. In other words, the selectivity characteristic should be such that the amplification of the sound signal is at all times a factor of 150-250 (or 44-48 dB) lower than that of the vision signal (fig. 7). (Again, of course, the precise value of the factor depends upon the strength-ratio of the vision and sound signals at the aerial terminals of the receiver.)

The selectivity characteristic of the stages of the receiver up to and including the sound detector is shown in fig. 8. It is seen that tuning is far more critical than in the case of intercarrier sound.

The adverse effect of interfering pulses in the sound can be reduced by including in the audio-frequency stage an interference suppressor which limits the amplitudes to a certain level. However, this cannot be done as effectively as in the case of frequency modulation, unless very complex circuits are employed.

Summary. A survey of the principal television standards at present in force is followed by an analysis of certain associated problems which are of special interest to the designer of television receivers. The points considered are: 1) Channel width; 2) Positive or negative picture modulation in relation to the visibility of interference and the effect of interfering pulses on synchronization and automatic gain control; 3) The system of sound transmission, that is to say, by frequency modulation or amplitude modulation; in connection with frequency modulation, the method of "intercarrier sound" is discussed.



A RADIOACTIVE-CONTAMINATION MONITOR FOR THE HANDS, FEET AND CLOTHING

by A. NEMET *), R. B. STEPHENS *) and W. A. BAYFIELD *).

621.387.4:614.8-084.4

In laboratories and establishments concerned with the handling of radioactive materials, or where ionizing radiations are present, the personnel are subjected to a number of health hazards which require that certain precautionary measures are taken. Among these are the detection and measurement of the sources of harmful radiations by means of special instruments normally referred to as monitors.

This article describes a monitor for the protection of personnel, which was developed some years ago for use in atomic energy establishments in England. The instrument is interesting for the diversity of the counting devices employed to meet the unusual operating conditions.

Instruments for monitoring radioactive hazards may be conveniently classified into the following main types ¹⁾:

*) Philips Balham Works Ltd., London

¹⁾ D. Taylor, Radioactivity surveying and monitoring instruments, J. Sci. Instr. 27, 81-88, 1950. See also R. B. Stephens, J. Brit. Inst. Radio Engrs. 14, 377-386, 1954.

1) *Personal monitors* for the measurement of accumulated radiation exposure (dosemeters) ²⁾.

2) *Survey meters* for measuring the radiation intensity in different parts of the laboratory. From the

²⁾ A recently developed instrument of this type is described by N. Warmoltz and P. P. M. Schampers, Philips tech. Rev. 16, 134-139, 1954/55 (No. 4).

radiation field plotted from these measurements, laboratory work can be planned so that the exposure of each individual worker is kept to a minimum.

3) *Contamination monitors* for the detection of radioactive materials. These instruments may be sub-classified as

a) *Area contamination monitors* for checking the contamination of working surfaces, apparatus etc., and if necessary, the air in the laboratory.

b) *Personnel contamination monitors* for checking contamination on the hands, feet and clothing.

An area monitor has previously been described in this Review³⁾. It is the purpose of this article to describe an instrument of the last-mentioned class, viz. a personnel contamination meter for monitoring the hands, feet and clothing⁴⁾. This instrument was developed some years ago by the X-ray and electro-medical laboratory of the Philips Balham Works in collaboration with the Atomic Energy Research Establishment at Harwell. The title photograph shows a number of the instruments in use in an atomic establishment in England. (Photograph reproduced from "Britain's Atomic Factories" by permission of the Comptroller of Her Majesty's Stationery Office.)

Design requirements of the monitor

The monitor is required to check that personnel working with radioactive materials or employed in an area where such materials are handled are free from health hazards due to activity inadvertently picked up on the hands or clothing. The health hazard may be due to penetrating γ radiation from a source of activity lodged, for example, in the clothing, or the activity may be ingested, where the hazard will depend on the amount absorbed by the body, the type of activity and its half-life and also on the "biological half-life" (a measure of the time the substance will remain within the body). Contamination with certain α -emitting "bone-seeking" elements is especially dangerous since the red and white corpuscles of the blood are destroyed at their source by the ionization. The tolerance levels for such ingested materials are therefore very low.

The only protection against these hazards is thorough washing of the hands and removal of any active material from clothing. To check the efficiency of these cleansing processes the contamination monitor is then used:

a) To check that the contamination of the hands is below tolerance level. This is done separately for

α and β - γ contamination, because the nature of the radiations is different and hence different types of detector are necessary.

b) To check that the clothing is free of contamination, again separately for α and for β - γ activity.

c) To check the level of activity on the soles of the shoes, due to active material picked up from the floor. This is done only for γ -contamination.

The essential features which distinguish the present instrument from other monitoring equipments are as follows:

1) A relatively large area (hands, clothing) has to be monitored.

2) The level of activity to be measured is low. In fact, it often corresponds to an activity of only the same order as the number of background counts due to cosmic rays and naturally-occurring radioactivity.

3) The relative positions of source and counter are not under very close control: for example, the active material may be lodged in crevices in the skin or under the fingernails.

4) The monitor has to be used by people of widely different intelligence levels and must therefore be fully automatic, foolproof and require no skill on the part of the user.

The problem of detecting and measuring low levels of activity under such conditions resolves itself into one of choosing the most suitable type of detectors and adapting their design to suit the given counting geometry.

The problem of establishing the tolerance levels, i.e. the maximum permissible activity ingested or deposited on the various parts of the body, is a difficult one and the levels have undergone changes during the past years as experience of physical and biological effects has accumulated. The instrument was therefore designed in such a way that the indication may be adjusted to conform with the prevailing tolerance levels. At the time the monitor was designed the following maximum permissible levels were adopted:

1) α -contamination on hands: 600 disintegrations per minute per hand.

2) β or γ -contamination on hands: 6000 disintegrations per minute per hand.

3) γ -contamination on feet: 500 000 disintegrations per minute per foot.

4) α -contamination on clothes: not specified; see below, p. 205.

5) β or γ -contamination on clothes: As 4), not specified, but see below, p. 204.

Choice of detectors

Owing to the different maximum permissible

³⁾ G. Hepp, A battery operated Geiger counter, Philips tech. Rev. 14, 369, 1952/53.

⁴⁾ F. S. Goulding and K. E. G. Perry, A hands and feet contamination monitor, *Atomics* 2, 43-50, 1951.

activities for α , β and γ , and the different counting geometry in the case of the hands, feet and clothing, the choice of the detectors for the various purposes poses a different problem in each case. These will now be discussed in turn.

Detectors for α -contamination on hands

The detection of α -activity on the hands might be achieved either with the aid of a scintillation counter or with a proportional counter. The former has the merit of a very high sensitivity and a short resolving time (although this is not important at low levels of activity). However, it is difficult to design a scintillation counter to cover a large counting area, an important requirement in this application.

The proportional counter, on the other hand, has the merit of simplicity of construction, sensitivity adequate for the purpose and reasonable stability during operation. It is also readily adaptable to large area counting. This type of counter has therefore been adopted for the α -monitoring of the hands.

It is true that proportional counters have certain disadvantages: microphony, small pulse height (of the order of 3 mV) requiring a high-gain amplifier, and high operating voltage (2.5 kV) which can lead to spurious pulses due to minute insulation breakdown in components. These points do not, however, outweigh its useful properties.

The proportional counter has the characteristic that the voltage pulse produced is proportional to the number of electrons initially produced, i.e. proportional to the energy of the incident particle. This is an extremely valuable feature, for, by suitable discrimination in the counting circuits, pulses of one kind may be counted in the presence of a high background of pulses of another kind but of lower energy. Thus in the present case, the use of these counters enables α -activity to be counted in the presence of a strong β -background.

In its simplest form the proportional counter consists of a cylindrical cathode surrounding a central anode wire of small diameter (see fig. 1). A source of high potential is connected

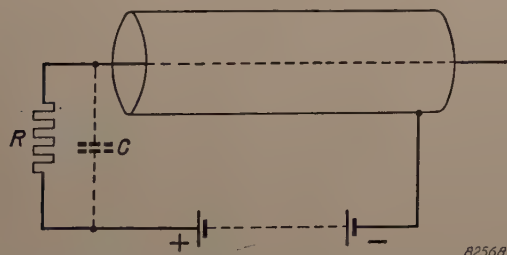


Fig. 1. Simple proportional counter. R resistance, C effective capacitance of counter.

across the counter via a resistor R in the anode lead. The dotted capacitor C represents the total capacitance of the counter and the resistor. The counter may be filled with air or other gas mixture.

Ionizing particles entering the counter and colliding with the gas molecules will produce free electrons which will be accelerated to the anode by the electric field. The collection of the electrons at the anode will give rise to a voltage pulse V across R of magnitude ^{6})

$$V = \frac{Ane}{C}$$

where n is the number of electrons formed in the initial ionizing event, e the charge on the electron, C the capacitance of the system and A the gas amplification factor.

The gas amplification arises because (assuming the anode voltage of the counter is sufficient) each initial electron entering the region of intense field near the anode wire will gain sufficient energy to produce further ionization by collision. Thus an avalanche of electrons is produced by each initial electron. The quantity A as defined above is the number of resulting electrons produced in this way.

It should be noted that if the applied voltage is small the gas amplification factor is unity and the counter becomes an ionization chamber. However by suitable choice of gas filling, pressure, voltage and diameter of anode wire, an amplification as high as 10^4 may be obtained.

For α -counting, some restriction is placed on the design of the proportional counter because an extremely thin window is necessary to minimize absorption. For this reason, air at atmospheric pressure has to be used as the gas filling. This of course means that the gas amplification is fixed since it is dependent on the choice of gas and the pressure.

The proportional counter used for monitoring the hands is of a flat construction, covering the whole area of the average hand. The design of this type of counter has been thoroughly treated by Simpson ^{6}). In the present instrument the construction is as shown in fig. 2. A number of fine tungsten

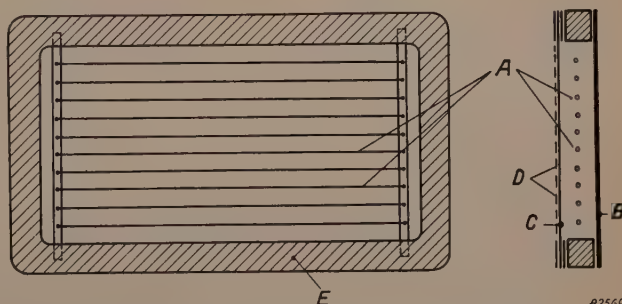


Fig. 2. Proportional counter of flat construction used for the counting of α activity on the hands. A tungsten anode wires 0.001" (25 μ) diameter, B metal backing plate, C aluminized paper window 8 μ thick, D protective metal grid. The polystyrene frame E is about 5" $\times$ 8" (125 $\times$ 200 mm).

^{5}) S. A. Korff, *Electron and nuclear counters*, Van Nostrand, N.Y. 1946, p. 34).

^{6}) J. A. Simpson, *Rev. sci. Instr.* **19**, 733, 1948.

wires 0.001 inches ($25\ \mu$) in diameter are stretched between two nickel rods fixed in a moulded polystyrene frame. These wires form the anode of the counter. The frame is sandwiched between a metal backing plate and a paper window 8 microns thick. The cathode consists of the backing plate and the paper window which is aluminised to render it conducting. A strong metal grid protects the window.

Four of these counters are used in the equipment, two to each hand. Their exact arrangement and mounting which are described later, gives a net counting efficiency (number of counts per disintegration) of the order of 25 %. The α tolerance level of 600 disintegrations/min therefore corresponds to a rate of about 75 counts/min for each counter.

Detectors for β and γ contamination of hands

The levels of β and γ activity which must be detected are of lower order than can be conveniently measured with ionization chambers or proportional counters. The most suitable type of detector for this purpose is the Geiger-Müller tube. It is not proposed to discuss the action of the Geiger-Müller tube in detail as this subject has been adequately dealt with elsewhere^{7), 8)}.

However, it may be noted in passing that in this tube the gas amplification is very high so that the initial ionization creates an avalanche of ions which spreads throughout the whole of the active volume of the tube. The result is that there is no longer any relation between the energy of the incident particle and the voltage pulse produced. The discharge has to be quenched, by either internal or external means.

In the contamination monitor, self-quenching ethyl bromide-filled Geiger-Müller tubes have been used, having an operating voltage of 1100 volts and a plateau (range of anode voltage over which the counting rate does not vary appreciably) about 100 V long. This type of a counter was chosen because they were readily available at the time the equipment was designed and their behaviour is well known.

For the measurement of β - and γ -activity of the hands the following arrangement was used. Four thin-walled cylindrical counters, one on either side of each hand, are arranged to scan the hand from the fingertips to the wrists. The scanning period is thirty seconds, during which time a total of 100 counts may be expected from a "tolerance hand" (= 100 disintegrations per sec). The net counting efficiency is therefore about 3 %. This

low figure is caused mainly by the geometry of the arrangement. The background counts from the four counters during this period would be about 80, so that the introduction of both, "tolerance hands" would increase the meter reading to rather more than twice the background value.

The net efficiency might have been raised by dispensing with the scanning system, and employing banks of counters above and below the hands sufficient in number to cover the whole area of the hands. This scheme, however, would suffer from the serious disadvantage that each counter would require to be separately adjusted in respect of its anode voltage and separately re-adjusted from time to time during the life of the tube as the quenching vapour was used up. About 16 counters would be involved, so this setting up and maintenance procedure would become very complicated.

Detectors for γ -contamination of feet

For measurement of the γ -activity on the shoe soles two large Geiger-Müller counters with an active length of about 10 inches (250 mm) and a diameter of $1\frac{1}{4}$ inch (30 mm), are fixed beneath the sheet steel platform on which the user of the instrument stands. Owing to their high energy the γ -rays are not appreciably attenuated by the platform.

The net efficiency of the arrangement is very low due partly to the poor geometry and partly to the inherently low efficiency of a Geiger-Müller counter for γ -rays. The geometry is such that the solid angle subtended by the counters is only a small fraction of 4π . Even so, activity corresponding to the tolerance level gives a meter reading (900 counts/min) which is double that due to background alone.

Detector for β - γ clothing probe

For β - γ monitoring of the clothing a similar type of Geiger-Müller counter is used to that for measuring the β - γ activity of the hands. The tube is mounted in the assembly shown in *fig. 3* and "scanning" of the clothing is done manually instead of automatically as in the β - γ hands unit. The net counting efficiency is such that 900 counts/min corresponds to the tolerance level, when the probe is held directly on the patch of activity. When not in use, the β - γ probe hangs on a hook on the left of the instrument (*fig. 4*).

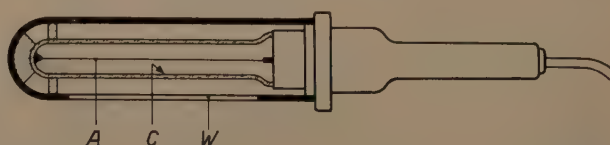


Fig. 3. β - γ clothing probe, consisting of a Geiger-Müller tube mounted in a protective assembly. *A* anode wire, *C* graphited glass cathode, *W* window in probe body.

⁷⁾ H. Friedman, *Proc. Inst. Radio Engrs.* **37**, 791, 1949.

⁸⁾ D. Taylor and J. Sharpe, *Nuclear particle and radiation detectors*, II. *Proc. Instr. Electr. Engrs.* **98**, Pt. II, 214, 1951.

Detector for a clothing probe

For α -monitoring of the clothing, again the possibility of using either an air proportional counter or a scintillation counter presents itself, both types having an adequate degree of sensitivity. An essential requirement of a clothing probe however is, that it should be able to withstand the rough handling it may be expected to receive when used by unskilled personnel. Proportional counters suffer from microphony due to vibration of the anode wires; this precludes their use in probes which will be subject to vibration and bumping during use.

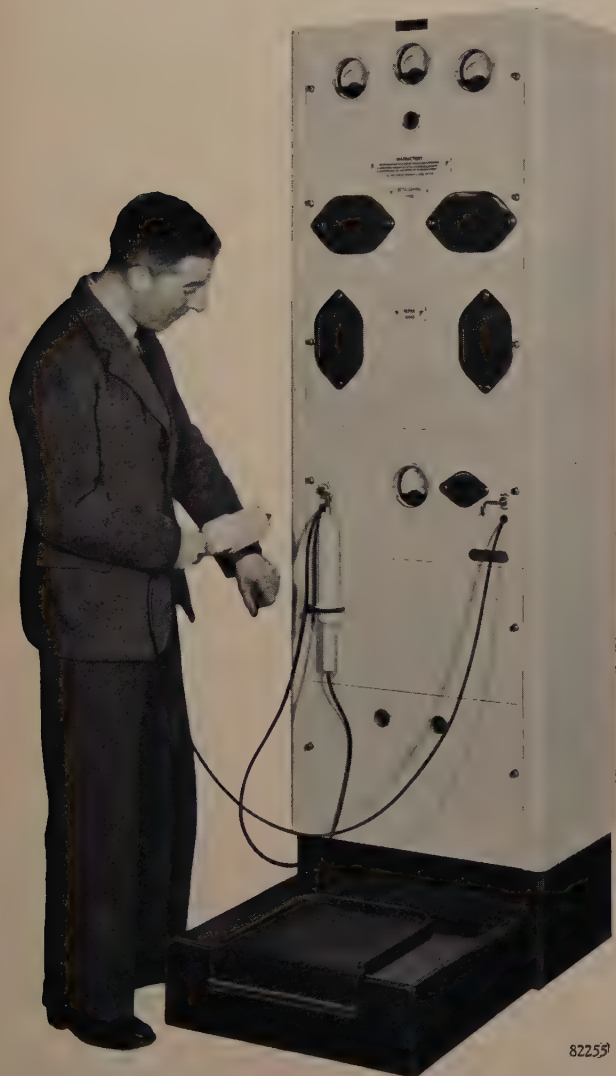


Fig. 4. Photograph of the monitor showing the α -probe in use.

A sketch of the scintillation counter used in the α -probe is shown in fig. 5. Essentially it consists of a thin light-tight window, a zinc sulphide screen and a photomultiplier. The window Al, whose function is to transmit α -particles but exclude external light from the photocell, consists of two sheets of aluminium foil each 8 microns in thickness. (Two

thicknesses of aluminium are used to reduce the possibility of light leakage through pin holes, which are unlikely to be opposite each other.) The zinc

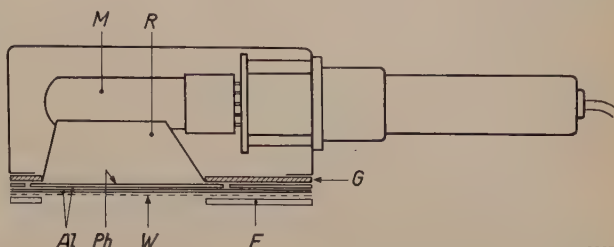


Fig. 5. Construction of the α clothing probe. *F* frame, *G* rubber gasket, *W* wire mesh protective cover, *Al* two aluminium foils each 8 μ thick, *Ph* phosphor (zinc sulphide), *R* reflector, *M* photo-multiplier.

sulphide screen *Ph* is activated with silver and coated on a "Perspex" sheet. The incident α -particles cause scintillations to occur on the screen; the light is reflected on to the photosensitive surface of the photomultiplier by means of a prism-shaped aluminium reflector *R*.

The net counting efficiency of this probe is such that about 300 counts/min corresponds to the tolerance level, when the probe is held directly on the active spot.

Operation and circuitry

Before discussing the actual construction of the instrument and its measuring circuits, it is instructive to first consider the measuring procedure and the various operations involved.

Measuring procedure

The user first pushes both hands through the vertical slots of the α -hand unit (see title photograph and fig. 4). The fingertips operate microswitches which energize a motor; this drives the vertically disposed α -counters on to the hands via a cam and lever mechanism, spring-mounted to allow for differing hand thicknesses. When the counters have closed on the hands, another microswitch energizes relays which switch off the motor and, after a short delay, trigger a timing circuit for the 15-second counting period. A warning light "Test now on" is also switched on. The integrated counts are indicated separately for each hand on the meters at the top left and right of the instrument (fig. 4). The meter readings build up until the end of the counting period, when the warning light extinguishes. The reading now on the meters indicate the α -contamination on the hands. Removal of the hands cancels the meter readings and causes the motor to open the counters in readiness for the next count. Should the hands be removed before the end of the 15-

second counting period an alarm rings. The alarm also rings if the α -contamination of either hand exceeds the tolerance level. The user must then wash his hands afresh and re-check with the monitor.

For measurement of the β - γ contamination, the hands are pushed through the horizontal slots in the β - γ hand unit (fig. 4). Switch bars at the rear of this unit are depressed by the fingertips to start the operation. The Geiger-Müller counters, mounted on a carriage, are then driven slowly so as to "scan" the hands. At the beginning of the scan, cam-operated contacts open-up the β - γ hand counting circuit (and also the γ -feet counting circuit, see below). At the end of its travel, the carriage carrying the counters switches off the motor and cuts out the counting circuit. A synchronous motor is used, so that the time taken for the scanning, and hence the duration of the counting period, is accurately determined; the period is adjusted to be 30 seconds. The β - γ contamination of the hands is indicated separately for each hand, on the same meters at the top of the instrument. Again, the alarm bell sounds if the contamination exceeds the tolerance level, or if the hands are removed before the end of the counting period.

The γ -count for the feet takes place simultaneously with the β - γ hands count, and the integrated count over the 30 second period is registered on the centre meter at the top of the instrument.

The probe units which come into operation only when removed from their hooks, register their counts on the meter on the probe panel, half-way down the instrument. (fig. 4).

Measuring circuits

Fig. 6 shows a block diagram of the counting and timing unit. The α -counters and the β - γ counters for the hands and the γ foot counters are connected via amplifiers to the counting circuits of this unit. The α -probe (scintillation screen + photomultiplier) and the β -probe (G.M. tube) are connected via amplifiers to a logarithmic count-rate meter and a loudspeaker.

The counting and timing unit provides for the control of the various operational sequences, the counting of pulses over a specified time interval, and registering the integrated count as a meter reading. Only three counting circuits are required for the five counting channels since the α -activity and the β - γ activity of the hands are not measured at the same time. Accordingly two of the counting circuits (with their associated meters) serve for both the α -measurement and the subsequent β - γ measurement.

Each counting circuit consists of a monostable flip-flop⁹⁾ which serves as a pulse shaper, followed by an integrating circuit which feeds the indicating meter. A pulse-shaper is essential when using this integrating circuit: without it the varying pulse heights would be integrated into a meter reading quite unrelated to the number of counts. The flip-flop also serves as a discriminator and rejects pulses below a certain height (e.g. noise): a pulse amplitude of about 5 V is necessary to trigger the flip-flop circuit.

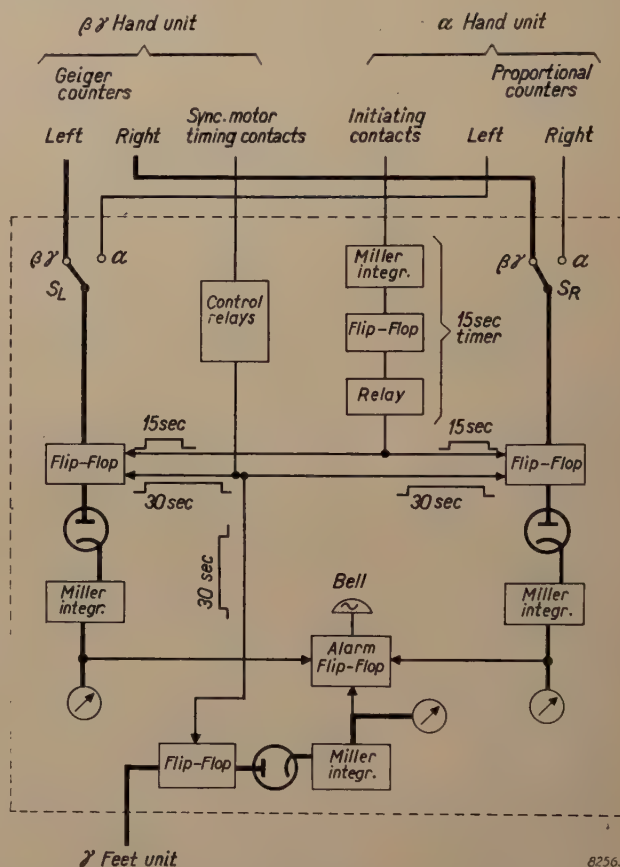


Fig. 6. Block diagram of the counting and timing unit. Three separate counting channels are provided. One of these counts γ pulses from the feet unit only, while the other two count either the α -activity or the β - γ activity of the hands, according to the position of the switches S_L , S_R . The bold lines indicate the routes of the counting pulses (S_L and S_R connected to β - γ unit). The counting period for α -activity of the hands is controlled by a 15 second timing unit based on a Miller integrator circuit. The counting period for the β - γ activity of the hands (and the γ activity of the feet) is controlled by a synchronous motor. An alarm circuit is connected to all three counting Miller integrators.

Integrated count circuit

The integration is performed by a Miller type of circuit¹⁰⁾ illustrated in fig. 7. The circuit consists

⁹⁾ See for example O. S. Puckle, Time bases and scanning generators, Chapman and Hall, 1951 (2nd Edn.) pp. 72-85.

¹⁰⁾ See for example, Philips tech. Rev. 12, 328-330, 1950/51, or O. S. Puckle, loc. cit., p. 340.

essentially of a pentode, which is normally cut-off by a switch which keeps the grid at a potential some 10 V. below that of the cathode. A capacitor C couples the anode to the grid. At the beginning of the counting period the switch is opened leaving the grid floating. The leakage currents are so small that the grid voltage does not drift appreciably—insufficient, anyway, to allow the valve to conduct,

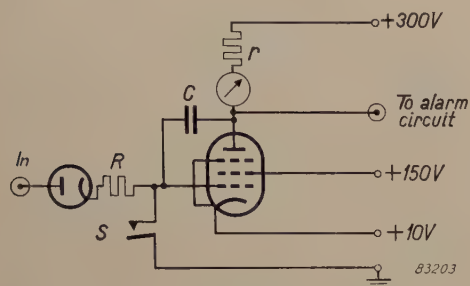


Fig. 7. Miller integrator circuit.

in the absence of pulses on the grid. The shaped counting pulses are fed to the grid via an isolating diode and the resistor R . Each pulse gives rise to an increment of charge on capacitor C which causes the anode current of the valve to increase by a fixed amount.

The charge entering the capacitor per pulse is $V_p t / R$ where V_p = pulse amplitude and t = pulse duration, so that the increase in potential across the capacitor is $V_p t / RC$ per pulse. Due to the gain of the valve the greater part of this voltage change occurs at the anode, so that the drop in anode voltage is nearly proportional to the increment of charge due to the incoming pulse. Hence the current through the meter is given by

$$I = N \cdot \frac{V_p t}{RCr},$$

where N is the total number of pulses arriving since the beginning of the counting period.

Three such integrated count circuits are used (fig. 6): one for the left hand (α or β - γ), one for the right hand (α or β - γ) and one for the feet (γ only). During the β - γ counting operation, the time constants (RC values) of the Miller integrators common to both α and β - γ channels are automatically changed to correct the meter scales for the difference in counting efficiency and in α and β - γ tolerance levels.

The 15 second timer

A Miller integrator circuit is also used for the accurate timing of the counting period for the α -activity of the hands. In this case the Miller

pentode is normally held in the conducting state (fig. 8) but the cathode current passes entirely through the screen resistor R_4 , because the suppressor grid is held some 150 V below the cathode potential so that no anode current can flow. When the hands are inserted into the instrument and the counters have closed on the hands, the switch S is opened and the suppressor rises to cathode potential. Anode current then flows and the screen current drops sharply. The voltage drop at the anode is fed via C to the grid, causing the valve to become nearly cut-off. At the same time, the rise of screen voltage triggers the flip-flop and energizes the timing relay which starts the counting period. The voltage on the grid begins to rise again due to the current entering via R_1 but again, due to the gain in the valve, the anode voltage drops more rapidly, at a rate determined to a first approximation by C and R_1 . When the anode bottoms (at about 20 V above cathode voltage) the grid voltage rises rapidly and the screen current increases. The screen voltage therefore drops and the flip-flop returns to its normal state, opening the timing relay and ending the counting period. The duration of the "run down" of the Miller circuit for the α -counting is chosen to be 15 sec.

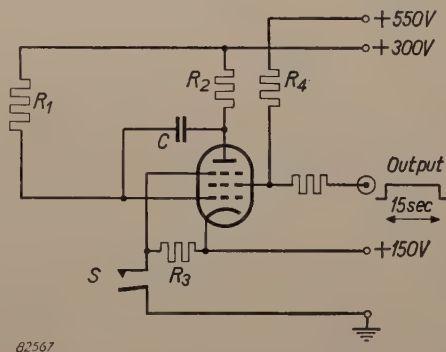


Fig. 8. Miller integrator circuit used for timing in 15 sec timer.

The alarm circuit

The anodes of the Miller integrator valves of the three counting circuits are coupled to another flip-flop. If any of the Miller valves suffers an excessive drop in anode voltage, the flip-flop is triggered, causing the alarm bell to ring. The flip-flop is so adjusted that it is triggered whenever the activity measured by any of the three counting circuits is above tolerance.

The alarm bell is also coupled via relays to the hand-operated switches on the α -hand unit and the β - γ hand unit, in order to give audible warning if either of the hands are removed during a counting period.

Construction and layout

The α -hand unit

The layout of the α -hand unit is seen in fig. 9. The fingertip-operated microswitches can be seen at the rear of the counters. The timing relay energized by the 15 second timer (fig. 6) removes the negative bias on the flip-flop circuits, permitting the counting pulses to pass through.

The output pulses (approx. 3 mV) from each pair of counters are fed to the input of a three-stage feedback amplifier with a gain of about 1600. This raises the pulse amplitudes to the 5 V necessary to trigger the flip-flops feeding the Miller integrators.

Due to the low level of the signal pulses at the counters, great care has to be taken to avoid spurious counts due to such causes as microphony in amplifiers and in the counters themselves, leakage across the insulators and accumulations of dust and small hairs in the counters. The effects of microphony in the system have been greatly reduced by giving the amplifier a low-frequency cut-off at about 10 kc/s. The insulators are cleaned with alcohol during assembly and the counters blown out with warm clean air to remove dust and any small hairs. Leakage due to condensation on the counters is minimized by heating resistors placed under them, which maintain a local ambient temperature of about 40 °C.

The β - γ hand unit

Fig. 10 shows an upper view of the β - γ hand unit. At the back of the flat grids are the switch-bars which start the counting operation. The cam-opera-



Fig. 9. Top view of α hands unit.

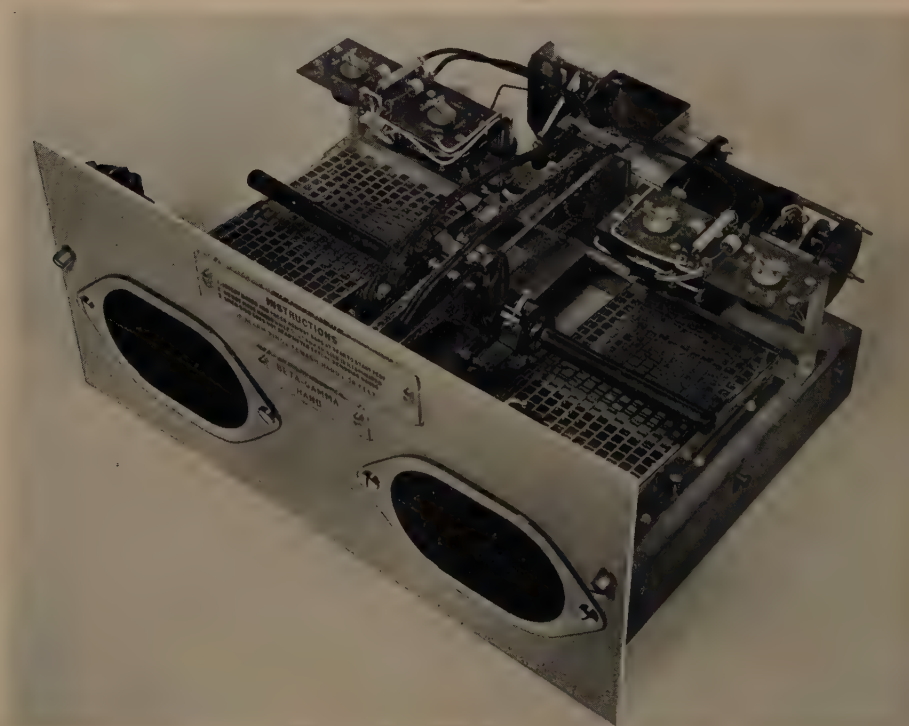


Fig. 10. Top view of β - γ hands unit.

ted contacts (at rear of unit) start the counting period proper by removing the negative bias on the flip-flops.

Since Geiger-Müller counters are used in this unit, the counter pulses are already fairly large and only little amplification is required before they are fed to the counting circuit. In fact a gain of about 5 is adequate and this is provided by a single valve in each channel.

As in the case of the β - γ hands counters, the pulses from the Geiger-Müller tubes measuring γ activity of the feet are large enough to require only one stage of amplification ($\times 5$). The counting and alarm circuit (fig. 6) are similar to those of the hand-counting channels.

The probe unit

In the probe unit a logarithmic counting rate circuit is employed for both the α -probe and the β - γ probe, as mentioned earlier. This permits counting over a wide range of activities without the necessity of changing the range (a useful feature in an instrument to be operated by unskilled persons). The circuit consists of a flip-flop so arranged that the duration of the current pulse from the normally cut-off valve diminishes as the frequency of the input pulses increases. This results in an approximately logarithmic scale giving reasonable reading accuracy over a counting rate range of 500:1. The meter itself is calibrated not in counts/sec but in "times tolerance". Full-scale on the meter corresponds to an activity of $100 \times$ tolerance level. A single stage of amplification is used to give the audible indication of the count rate on the loudspeaker.

When the β -probe is removed from its hook (fig. 4), a microswitch raises the voltage on the Geiger-Müller tube by about 300 V so bringing it on to the correct operating point of its characteristic. Counting then begins. Only a single stage of amplification is required for the pulses to trigger the count-rate circuit. By maintaining the counter voltage about 300 V below normal while not in use, the life of the counters is conserved. This procedure has been adopted with all the Geiger-Müller tubes in the apparatus.

When the α -probe is unhooked, a microswitch energizes a relay which switches over the input of the logarithmic count rate circuit so that it receives pulses from the amplifier of the photomultiplier. The relay also changes the time constant of the flip-flop so that the duration of its current pulses is altered to give a meter scale conforming with the α -tolerance level. The anode resistance for the

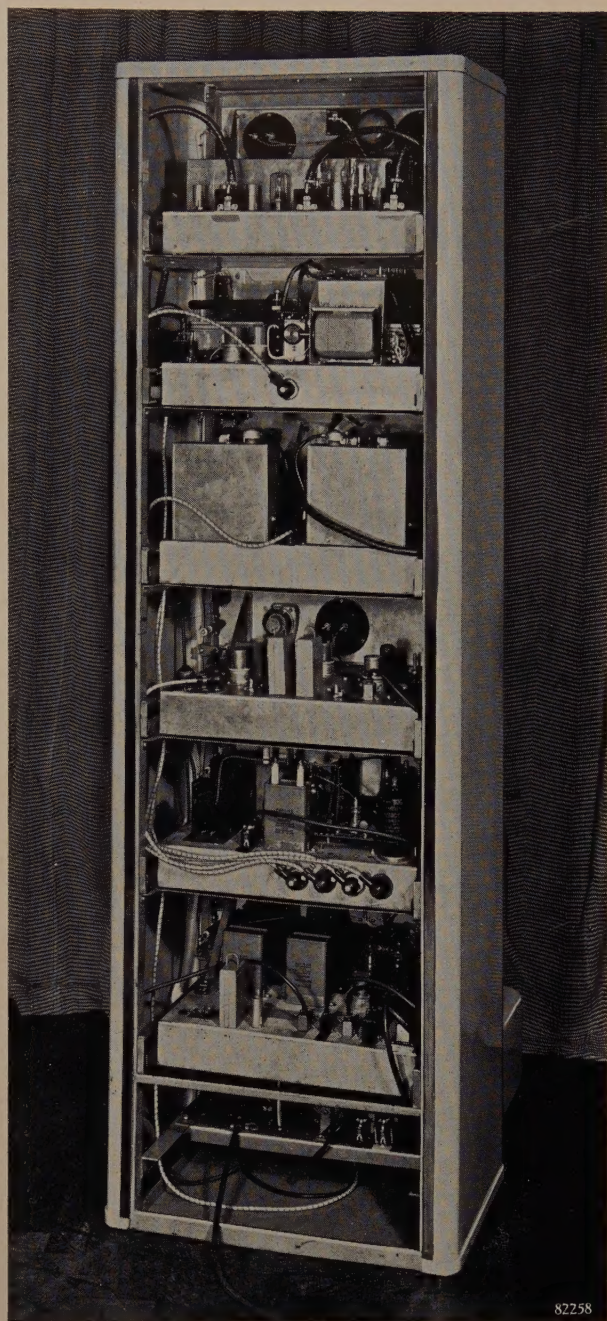


Fig. 11. Rear view of complete instrument. From top to bottom: counting and timing unit, β - γ hands unit, α hands unit, probe unit, E.H.T. power pack for counters (2500 V and 1200 V), power pack for valves (300 V), power pack for relays (50 V). The platform in front of the instrument contains the Geiger Müller counters for measuring γ -activity on the feet.

multiplier is situated in the main unit, so that the same cable carrying the high tension supply also carries the output pulses fed to the ratemeter. A length of concentric cable of low capacitance is used so as to obtain as large a pulse height as possible.

General layout

The layout of the complete instrument can be seen from the rear view shown in fig. 11. The various

counting and indicating units occupy the top four chassis. At the bottom of the rack is a 50 V power unit supplying the relays of the instrument. Immediately above this is the 300 V D.C. stabilized power supply for the valves of the monitor. This circuit is of conventional design, using a hard valve rectifier and a series-parallel type of stabilizer¹²⁾.

The E.H.T. power pack (third unit from bottom) provides the stabilized D.C. supplies for the various counters, viz. a nominal 1200 V supply for all the Geiger-Müller counters and the photo-multiplier of the α -probe and a nominal 2500 V supply for the proportional counters. Both these supplies are also stabilized by means of series-parallel stabilizers. The intermediate anodes of the photo-multiplier are supplied from a high resistance potential divider connected across the 1200 V supply.

For ease of servicing, all the units of the instrument are mounted on sliding arms so that they can be withdrawn from the front of the apparatus. Interconnections between the units are made by plug and socket connections, with sufficient spare cable to allow the units to be pulled forward. When

the units have been so pulled forward, a system of interlocks ensures that the high voltage supplies are disconnected.

All labels and escutheons are made detachable so that they can be easily decontaminated. The lines of the apparatus have been made as smooth as possible so as to avoid crevices where contaminated dust might lodge and be difficult to remove.

Thanks are due to the Director of the Atomic Energy Research Establishment at Harwell for permission to publish this article.

Summary. The need for an instrument to monitor the hands, feet and clothing of personnel working with or near radioactive materials is explained with reference to the health hazards involved and the safe tolerance levels. After an outline of the requirements of such a monitor, the detectors for the different measurements are discussed. Proportional counters are used to measure α -activity on the hands; Geiger-Müller counters are used for β , γ -activity on the hands and the clothing, and for γ -activity on the feet; for α -activity on the clothes a scintillation counter is used. Some of the timing and counting circuits are described, notably the Miller integrator circuit on which the hands and feet measurements are based. The probe units for measurement of activity on the clothing use a logarithmic count-rate circuit. Special emphasis is laid on the automatic operation of the instrument, which requires no skill on the part of the user. The construction of some of the units and their layout are briefly treated.

¹²⁾ See for example, H. J. Lindenhovius and H. Rinia, Philips tech. Rev. 6, 54-61, 1941; or F. A. Benson, Voltage Stabilizers (Electronic Engineering, London, 1950).

ABSTRACTS OF RECENT SCIENTIFIC PUBLICATIONS OF N.V. PHILIPS' GLOEILAMPENFABRIEKEN

Reprints of these papers not marked with an asterisk * can be obtained free of charge upon application to the Philips Electrical Ltd., Century House, Shaftesbury Avenue, London W.C. 2.

R 222: W. K. Westmijze: Studies on magnetic recording IV (Philips Res. Rep. 8, 343-366, 1953, No. 5).

Concluding article of the series **R 213**, **214** and **217**. A comparison is made between numerical values given by the formulae derived earlier and the experimental data. Special consideration is given to the relation of the output to the biasing current and to the frequency and the distortion as a function of signal current and biasing current. Finally, changes of a magnetic recording with time are discussed; in particular the magnetization by weak magnetic fields from adjacent layers of tape. Measurements of this so-called print effect are compared with the magnetic lag calculated from the Brownian movement of particles in a field of force. The logarithmic increase of the print effect with time is explained in this way.

R 223: H. van de Weg: Quantizing noise of a single integration delta modulation system with an N-digit code. (Philips Res. Rep. 8, 367-385, 1953, No. 5).

In order to compare the delta-modulation system (ΔM system) with the pulse code modulation system (PCM system) as regards the bandwidth required to obtain a certain signal-to-quantizing-noise ratio, the quantizing noise is calculated for a single-integration ΔM system. The possibility that the difference between signal and approximation may be coded in a more-digit binary code is also considered. In accordance with Bennett, the information signal is chosen to consist of a noise function, in order to obtain average quantizing-noise spectra that are smooth functions of frequency. Because in ΔM the signal is not limited in amplitude but in slope, the signal-to-noise ratio depends on the frequency

spectrum of the applied signals in another way than is the case with PCM. It turns out that for speech transmission, the ΔM system has more favourable properties than PCM, if the same sampling frequency and number of digits are taken in both cases. An analytical expression is derived for the quantizing-noise spectrum that is valid for an arbitrary information signal.

- R 224:** P. Zalm and H. A. Klasens: A new 6100-Å band in zinc orthosilicate activated with manganese (Philips Res. Rep. **8**, 386-392, 1953, No. 5).

When phosphorus is incorporated together with manganese into zinc orthosilicate by heating at relatively low temperatures (820 °C), a phosphor is obtained with an emission band at 6100 Å next to the normal green Mn emission at 5250 Å. The properties of this new emission band are discussed and compared with those of similar bands in other manganese-activated zinc silicates.

- R 225:** A. Bril, H. A. Klasens and P. Zalm: A new method to determine short decay times of phosphors excited with ultraviolet light (Philips Res. Rep. **8**, 393-396, 1953, No. 5).

A new and simple method is described to determine decay times of phosphors using a pulsed cathode-ray tube with ultraviolet-emitting phosphors of short decay time as light source. The decay time of Sb-activated halophosphates was found to be 5×10^{-6} sec.

- R 226:** W. de Groot: Some remarks about the so-called Crova wavelength (Philips Res. Rep. **8**, 401-410, 1953, No. 6).

It is shown that it is of minor importance whether the Crova wavelength λ_c is defined with the aid of Planck's or Wien's radiation formula, both definitions leading to approximately the same result. If $V(\lambda)$, the relative spectral luminous efficiency, is approximated by a Pearson function $A\lambda^{-p}\exp(-q/\lambda)$, λ_c is a linear function of T^{-1} . It is shown that the relative luminous efficiency of a perfect radiator is approximately maximum if $\lambda_c T = c_2/4$ or $\lambda_m T = c_2/4$, in which λ_m is the wavelength for which $V(\lambda) = 1$. It is further shown that the theoretical value of the maximum spectral luminous efficiency, K_m , as deduced from the definition of the candela, depends on the values assigned to c_1 and to the ratio c_2/T_{Au} (T_{Au} = melting temperature of gold). To a first approximation,

$$\frac{dK_m}{K_m} = -\frac{dc_1}{c_1} + \frac{1}{\lambda_c(T_{Pt})} d\frac{c_2}{T_{Au}}.$$

The luminance of a perfect radiator is given in terms of λ_c .

- R 227:** F. K. du Pré: The counting loss of a Geiger counter with periodic arrival rate of quanta (Philips Res. Rep. **8**, 411-418, 1953, No. 6).

A formula is derived for the counting loss of a Geiger counter with arbitrary dead time, exposed to periodic X-radiation of arbitrary waveform. An "extended" dead time is assumed. In particular, the small-loss case is considered, since then the results are independent of the type of dead-time mechanism. The small-loss corrections obtained by different authors are shown to be special cases of the general formula.

- R 228:** F. W. Gundlach: Laufzeiterscheinungen der Diode im Anlaufstromgebiet (Philips Res. Rep. **8**, 419-426, 1953, No. 6). (Transit-time phenomena in the exponential region of the diode characteristic; in German.)

Where a diode is in the exponential region of its characteristic (minute electrode distances, negative anode voltage), the convection current at its anode may be calculated by considering the transit-time phenomena at small a.c. voltages. The conductance of the diode is ascertained; it turns out the electrons which do not hit the anode provide a particularly strong contribution. The discrepancies of earlier publications are pointed out. The values calculated agree reasonably well with the measurements published by other authors.

- R 229:** H. C. Hamaker: The efficiency of sequential sampling for attributes, Part II. Practical applications (Philips Res. Rep. **8**, 426-433, 1953, No. 6).

The practical consequences of the theory developed in part I (see **R 208**) are considered. It is shown that the simplified equations (valid under Poisson conditions) can be used to construct a slide rule from which the operating characteristic of a sampling system can be read off at once when the parameters h_o and p_o are given. Furthermore, graphs are constructed which permit an easy and straightforward transition from the parameters p_o and h_o to the more common parameters such as AQL, AOQL, etc.

- R 230:** J. L. H. Jonker: The angular distribution of the secondary electrons of soot (Philips Res. Rep. **8**, 434-440, 1953, No. 6).

The angular distribution of the secondary electrons of soot is measured with the same equipment as was used before to measure poly-crystalline

nickel (see **R 175**). The results for soot and for nickel are compared.

H 231: H. A. Klasens, P. Zalm, F. O. Huysman: The manganese emission in ABF_3 compounds (Philips Res. Rep. **8**, 441-451, 1953, No. 6).

A number of compounds of the composition ABF_3 were made with $\text{A} = \text{Na, K, Rb, Cs}$ and $\text{B} = \text{Mg, Zn, Cd, Ca, Sr}$. These substances have the perovskite structure when the corrected tolerance factor $1.15 (R_A + R_F)/(R_B + R_F)\sqrt{2}$ lies between 0.9 and 1.1 (R_A etc. are ionic radii). They are fluorescent under cathode-ray excitation when activated with Mn. The colour of the Mn emission varies between orange and green. It shifts to shorter wavelengths with increasing Mn-F distance. An attempt is made to explain this shift.

R 232: J. Volger, J. M. Stevels and C. van Amerongen: The dielectric relaxation of glass and the pseudo-capacity of metal-to-glass interfaces, measured at extremely low frequen-

cies (Philips Res. Rep. **8**, 452-470, 1953, No. 6).

The dispersion of the dielectric constant of glass in the L.F. region has been investigated. The main relaxation time may be explained as the reciprocal transition probability of Na^+ ions jumping between adjacent interstices. Extremely high electrode capacitances have been detected, which are frequency and temperature dependent. These values are in qualitative agreement with a simple formula derived for the dynamic values of double-layer capacitances.

R 233: A. van Weel: Measurements of phase angles (Philips Res. Rep. **8**, 471-475, 1953, No. 6).

Phase angles are measured from the frequency variation of an oscillating circuit, caused by introducing the unknown phase angle into the closed loop of the oscillator circuit. High sensitivity, good accuracy and direct indication on a calibrated scale are some of the features of the system (cf. Philips tech. Rev. **15**, 307-316, 1953/54).
